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SOCIETY AND RELATED ACTIVITIES

Automotive Meeting

Members of the AMERICAN WELDING SOCIETY are invited to attend and participate in the S. A. E. International Automotive Engineering Congress at the Palmer House in Chicago, Illinois, August 28 to September 4, 1933. The program will include technical phases of a wide field of automotive enterprise.

German Exposition

The Board of Managers of the Verein Elektrowärme-Ausstellung e.V. (Registered Association for Holding an Exposition of Applications of Electric Heat) of Essen, Germany, announce that an exposition will be held in Essen, Germany, between July 1 and August 13, 1933.

The purpose is to exhibit the various devices used and the processes employed whereby heat in the form of electrical energy is now serving the purposes of mankind. The exposition will be presented in both a "Technical" and in a "Popular" manner. Wherever possible the equipment will be shown in operation.

The exhibition will take place in special exposition buildings located at Essen in the heart of the Ruhr industrial district, where the greatest consumption in Germany of electrical energy in the form of heat has been developed.

The principal subdivisions of the Exposition are: (*A*) electrical heating in the household; (*B*) electrical heating in the large-scale preparation of foodstuffs (restaurants, hotels, etc.); (*C*) electrical heating in industry—(heat treating—electrical welding, etc.); (*D*) other fields which will be covered consist of electric heating in various trades; in agriculture, in household heating, in refrigeration and in medicine.

The exposition is sponsored by a great number of the most prominent German interests in this field. Special committees have been organized to develop the interest in each particular subdivided branch.

Obituary

Alexander Churchward, charter member of the AMERICAN WELDING SOCIETY, died of heart disease on Tuesday, July 11th, at his home, 411 Redmond Road, South Orange, N. J. He was nearly 61 years old. Mr. Churchward was born in Ceylon, India. He obtained his education in England and came to the United States when he was eighteen years old, entering the employ of the General Electric Company. He subsequently worked for Henry Ford and Thomas A. Edison. More than 200 patents in the electrical, radio and automotive fields were obtained by him. For the past twelve years he has been Technical Director of the Wilson Welder & Metals Company. He has served on numerous committees of the Society and was active in its research work. He assisted in the formation of the AMERICAN WELDING SOCIETY in 1919.

SECTION ACTIVITIES

CHICAGO

The Chicago Section provided an interesting program on June 29th during Engineers' Week at the Congress Hotel.

The speakers and subjects included:

A. L. Wilson, Mississippi Valley Structural Steel Co. on Design in Construction of the Two Sky Ride Towers (with particular reference made to economies of welded fabrication and the procedure employed).

J. M. Jardine, Western Welding and Boiler Repair Co. on Interesting Applications of the Welding, Flame Cutting and Allied Processes in Evidence at the Fair. (This paper included detailed descriptions about outstanding welded fabrication.)

The two papers were followed by luncheon and a round-table discussion.

DETROIT

The following appointments have been made by the Detroit Section to serve on National Committees for the years 1933–1934:

National Board of Directors:

Col. A. S. Douglas, Construction Engineer, Detroit Edison Company.

Revision of By-Laws:

C. Levon Eksergian, Chief Engineer, Budd Wheel Company.

Membership Committee:

Sidney M. Harvey, President, Electric Welding Machine Company.

NEW YORK

At a meeting held on June 6th the following officers of the New York Section were elected to office for term of 1933–1934.

Chairman—H. H. Moss, Linde Air Products Co.

1st Vice-Chairman—S. S. Scott, New York Navy Yard.

2nd Vice-Chairman—P. W. Swain, *Power*.

Secretary-Treas.—A. F. Keogh, Sound Welding Co.

Executive Committee

For three years

J. B. Tinnon, Metal & Thermit Corp.
R. W. Boggs, Union Carbide Co.
F. Eder, R. W. Hunt Company
M. Male, U. S. Steel Corp.

For two years

E. Vom Steeg, General Electric Co.
H. M. Priest, American Bridge Co.
S. L. Jacobson, Charles Mayer.
J. W. Gray, Westinghouse Elec. & Mfg. Co.

For one year

C. Kandel, Craftsweld Equipment Co.
W. P. Curley, Tube-Turns, Inc.
G. N. Bull, Lincoln Electric Co.
F. E. Rogers, Air Reduction Sales Co.

Representative on National Board of Directors: T. C. Fetherston, Linde Air Products Co.

Representative on National Revision of By-Laws Committee: J. B. Tinnon.

SERVICES AVAILABLE

A-146. Welding Engineer, college graduate, 18 years' experience in steel fabrication, last 6 years devoted exclusively to the application of electric welding; competent to handle any branch of the program of applying electric welding to the design, fabrication and erection of structural steel and ornamental iron.

A-199. Welding Engineer, foreman and supervisor desires position. Have had nine years' general electrical, mechanical engineering experience with the Denison Electrical Engineering Company. This was followed by one year with the New York, New Haven & Hartford R. R. on the installation of electric railway car and equipment. For seven years was connected with various engineering and manufacturing companies as foreman in charge of manufacturing all kinds of electrical equipment. Since 1910 have been connected with the Pittsfield Works of the General Electric Company. Was in charge of testing equipment, including repairs and maintenance, and later in charge of development of arc welding to tank manufacture. Have been in charge of force of two hundred men, covering range of application of electric arc, resistance and gas welding.

A-200. Gas and electric welder. Pipe work specialty and all shop work. Have been also employed as welding inspector.

TENTATIVE PROGRAM
THIRTEENTH FALL MEETING
AMERICAN WELDING SOCIETY
OCTOBER 2-6, 1933

Book-Cadillac Hotel
Detroit, Mich.

Important Notice

Members and guests are requested to register immediately upon arrival, Book-Cadillac Hotel, as admission to Exposition and participation in social events and inspection trips will be by badge only.

Upon registering you will be furnished with copy of the Journal containing papers to be presented at the technical sessions. The supply of Journals is limited, one to each registrant, and on this account you are urged to retain your copy throughout the meeting.

Technical sessions and committee meetings will be held at the Book-Cadillac Hotel.

All sessions will start promptly as scheduled.

There will be no stenotype reporter. Members of the Society desiring to discuss papers are urgently requested to prepare their discussion in writing in advance of the meeting and to send copies to headquarters as those preparing written discussion will be given preference at the sessions. Members and guests giving extemporaneous discussion at meetings should forward a written transcript of their discussion as soon after the meeting as possible.

Monday, October 2nd

Morning

REGISTRATION

Facilities will be provided throughout the week from 9:30 A.M. to 5:00 P.M., commencing Monday, October 2nd.

Afternoon

OPENING SESSION

1:45 P.M. Presiding Officer—M. P. Bailey, Chairman, Detroit Section.

Address of welcome by Mayor and response.

TECHNICAL SESSION

2:15 P.M. Presiding Officer—Frank P. McKibben, President.

A paper on "Gas Cutting of Structural Steel." (Author to be announced later.)

"Impact Resistance of Welded Joints—A Survey of the Literature," by W. Spraragen.

"Use of Shielded Carbon Arc in Class I Welding," by E. W. P. Smith, Consulting Engineer, The Lincoln Electric Co.

Evening

6:30 P.M. Dinner meeting, Board of Directors, Book-Cadillac Hotel.

Tuesday, October 3rd

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer—J. J. Crowe, Senior Vice-President.

"Manufacture of Small Everdur Tanks by Welding," by Ira T. Hook, American Brass Co.

"Welding of Chrome Alloy Steels," by W. B. Miller, Union Carbide & Carbon Res. Labs.

"Welding of Oxygen-Free Copper," by R. W. Summey, U. S. Metals Refining Company.

"Gas Welding of Aluminum." (Author to be announced later.)

"Welding of Non-Ferrous Metals and Alloy Steel," by representative, Thomson-Gibb Co.

"Atomic Hydrogen Welded Tubing," by E. Riemenschneider, Midland Steel Co.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—C. A. Adams, Director, American Bureau of Welding.

FUNDAMENTAL RESEARCH IN WELDING

"Physical Properties of Welded Cast Steel," by Chas. H. Jennings, Westinghouse Electric & Manufacturing Co.

"Tensile Tests of Welded and Riveted Structural Members," by R. P. Davis, Dean, West Virginia University.

"Electric Arc Welding under Water," by N. S. Hibshman and C. D. Jensen, Asst. Profs., Electrical and Civil Eng., Lehigh University, and W. R. Harvey, Asst. Prof,, Lehigh University.

"The Effects of Motor Reactions in Electric Welding," by W. R. Woolrich, Prof., Mech. Eng., J. Tarboux, Prof. Elec. Eng., University of Tennessee and C. T. Raymo and W. B. Parker.

"Fatigue of Metals," by G. E. Thornton, Dept. of Mech. Eng., The State College of Washington.

"Internal Stresses in Welds," by C. T. Schwarze, Dept. of Civil Eng., New York University.

Evening

7:30 P.M. Book-Cadillac Hotel. Conference and meeting of Fundamental Research Committee, American Bureau of Welding. H. M. Hobart, Chairman, presiding.

This conference is scheduled for the benefit of university research workers in the fundamentals of welding.

Wednesday, October 4th

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer. (To be announced later.)

RESISTANCE WELDING SESSION

"Development and Application of Automatic Welding Controls," by H. W. Roth, President, Controloweld, Inc.

"Controlled Welding," by O. C. Frederick, General Electric Company.

"Precision Spot Welding with Tube-Controlled Contactors," by C. Stansbury, Engineering Dept., Cutler Hammer, Inc.

"Continuous Seam Welding of Pressure Vessels by the Resistance Method," by representative, A. O. Smith Corp.

Afternoon

INSPECTION TRIP

1:15 P.M. Leaving Book-Cadillac Hotel.

This inspection trip will be arranged by the Detroit Section and may include automobile body plants. Trip may also include a motor ride to Belle Isle, Grosse Pointe, Palmer Woods and a few other interesting places.

Thursday, October 5th

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer. (To be announced later.)

"Shipbuilding Welding," by G. H. Moore, Jr., Newport News Shipbuilding & Dry Dock Co.

"Welding of Structural Nickel Steel," by W. L. Warner, Watertown Arsenal.

"Welding of Galvanized Steel," by Leon C. Bibber, Bureau of Construction & Repair, Navy Dept.

"An Aircraft Manufacturer's Experience with Welding Quality Control," by T. H. Speller, Curtiss Aeroplane & Motor Co., Inc.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—M. P. Bailey, Chairman, Detroit Section.

"Shop Setup for Pre-fabrication of Welded Machinery," by C. A. Bowlus, Kelvinator Co.

"Thermit Welding of Rail under Traffic," by J. H. Deppeler, Metal & Thermit Corp.

"Pressure Regulators," by J. J. Crowe, Air Reduction Sales Co.

"Welding in the Automotive Industry." Author to be announced later.

"Automobile Welding." Author to be announced later.

Evening

7:00 P. M. Annual Banquet followed by dancing. Book-Cadillac Hotel.

Investigations on Phenomena of Arc Welding and Gas Cutting by Slow-Motion Pictures

By PROF. DR.-ING. A. HILPERT

†Prepared for the Fundamental Research Committee, A. B. W. Prof. Hilpert is Director of the Welding Laboratory of the Technical University, Berlin.

SOME years ago no welding expert had the faintest idea of just what took place in the electric welding arc. Especially the opinions about the transition of the material in the arc were quite different. While some of them thought that the material goes over as vapor or even as smoke, others had the opinion that the transition proceeds by single drops or even in a continuous flowing. The knowledge of these events is of great importance for the selection and the manufacturing of electrodes, especially of the heavily coated electrodes, as the movement of the slags has to be observed.

For the final solving of these questions a great number of slow-motion pictures were taken in the Welding Laboratory of the Technical University, Berlin. The success of these pictures enabled us also in the same way to obtain information on the phenomena of gas cutting as well as the visible appearance of the oxygen beam. The second part of this article will deal with such pictures of gas cutting.

Part I. The Events in the Welding Arc

The first attempts to take slow-motion pictures of the welding arc were made in 1927 with the slow-motion camera of R. Thun, Berlin. This camera can take some thousand pictures per second by a special locking apparatus. The film runs at a high speed uninterruptedly through the camera. The exposing of the film is done by turning a carved disk. Therefore, the time of exposure is so short that the theoretical expectancy of disfiguration of the picture practically never happens.

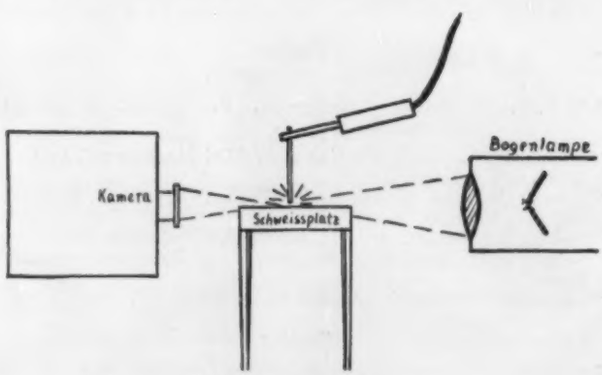


Fig. 2—Outshining Method

Fig. 1—Infra-Red Picture of a Drop

Fig. 3—Picture of a Drop Taken by the Outshining Method

As the film runs with 10–12 M./sec. and as only the fourth part of the normal size of the film is used the mentioned high numbers of pictures can be reached. The circumstances in this case were specially favorable, for the enormous quantity of light makes possible a very short time of exposure.

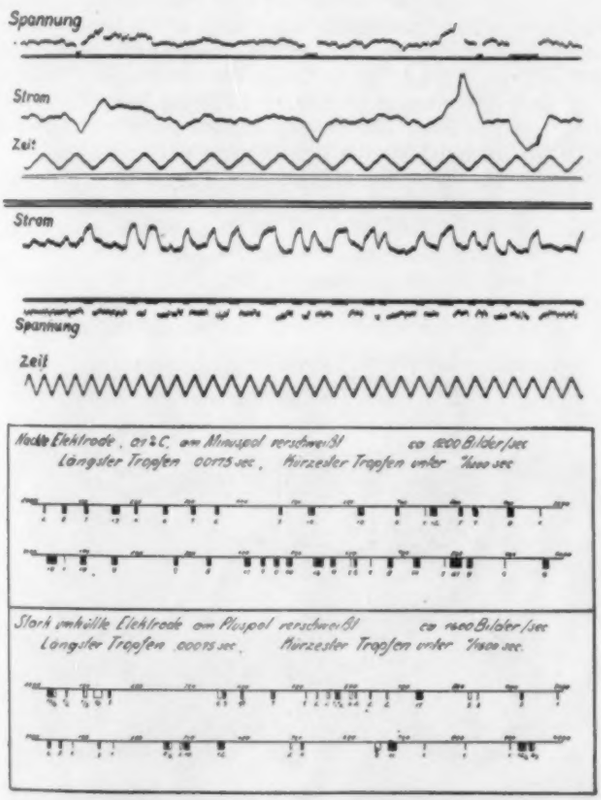
The first film which was taken by this camera was produced in Nov. 1927. The pictures brought a disappointment in so far as there was only a strong dancing and an occasional extinguishing of the arc in spite of a retardation in the ratio of forty times, but there was nothing to see of the time or the way of the transition. Nowadays it is well known that the occasional extinguishing of the arc is explained by the short circuits made by drops of material. But because the arc extinguishes on account of these short circuits there is

darkness in the moment of the transition, so that nothing can be recognized.

Nearly at the same time one tried in America to use a film sensitive for infra-red (most sensitive for 8100Å/E, besides blue and violet). So the heat rays are used for exposing the film. This method has the advantage that the liquid parts of electrode and bead, as well as the drop, give sufficient light and heat rays for getting a picture in the right way. On account of the imperfection of the apparatus and of the little sensitiveness of the film only a number of pictures of 60/sec. could be reached. Therefore, details were difficult to recognize, though this film was a great aid in these investigations.

Among the pictures taken later on in the Welding Laboratory of the Technical University, Berlin, this method was used for comparison. The improved camera and the higher sensitiveness of the Agfa-R-film made it

Fig. 4—Welding Oscillogram



Nackte Elektrode, ca 2 C, am Minuspol verschweißt ca 1200 Bilder/sec
Längster Tropfen 0,015 sec, Kürzester Tropfen unter 1/1000 sec
Stark umhüllte Elektrode am Pluspol verschweißt ca 1000 Bilder/sec
Längster Tropfen 0,015 sec, Kürzester Tropfen unter 1/1000 sec

Fig. 7—Diagram of Slow-Motion Pictures of the Electric Welding Arc

possible to take very good and clear pictures of a very great number of pictures per second. But these pictures were not quite so clear as those taken by the outshining method of Thun, Fig. 1. For further researches it was greatly important to make ineffectual the extremely disturbing brightness of the arc which obscured the phenomena taking place. At the same time it was necessary to illuminate the object while the arc was extinguishing. For this purpose R. Thun developed his outstanding method, D. R. P. In this case the welding arc and its surroundings are illuminated by an exceptionally strong arc light, so that a great arc lamp gives its light straight into the lens of the camera along the optical axis, Fig. 2. Now the value of light of the welding arc is only a little more than the general brightness. Here electrode, drop and bead appear as silhouettes while the arc comes out as a very bright spot on a bright background, Fig. 3.

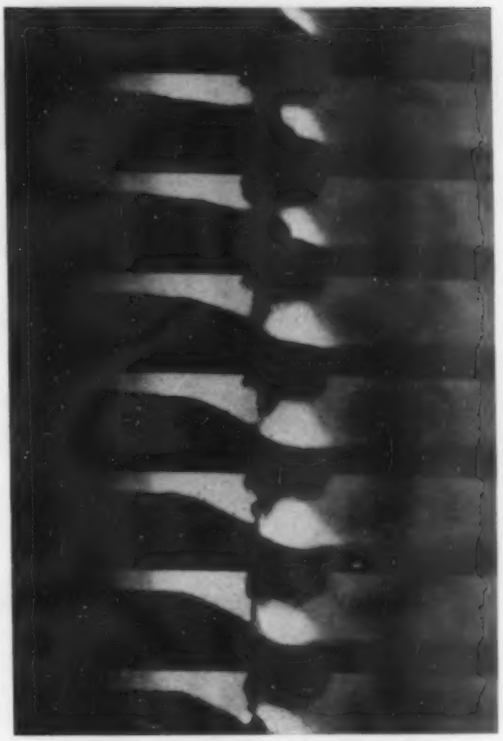


Fig. 5—Drop of Pure Slag

New pictures were taken in 1929 by this method which had the desired success. The transition of the drops could be observed very distinctly as silhouettes, because there was a sufficient brightness during the short circuits, so that the events could also be seen without the arc.

In connection with the researches made with the oscillograph by Bung in 1926, the welding oscillogram was taken at the same time as the moving picture. This experiment brought the ratification of the supposition of Bung; the real transition of the material must happen during the short circuits. On the voltage curve and on the current curve of the oscillogram, Fig. 4, irregularly following short circuits can be distinguished, and there Bung supposed the transitions of the material. By synchronizing the film and the oscillogram it was possible to compare the electric events with the visible ones. Here it was proved that the transition always happened during the short circuits, which really is so self-evident.

Now different electrodes and materials could systematically be researched after having removed the difficulties of the photographic method. While the first pictures were taken from manual weldings, an automatic

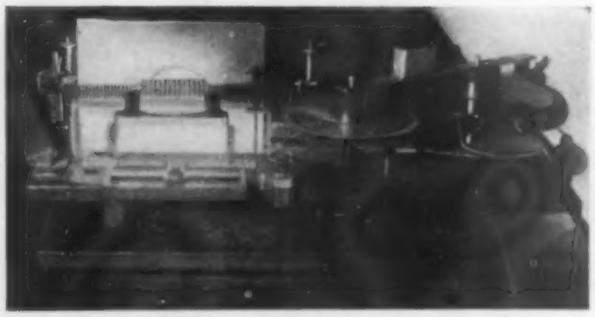


Fig. 6—Counting Apparatus

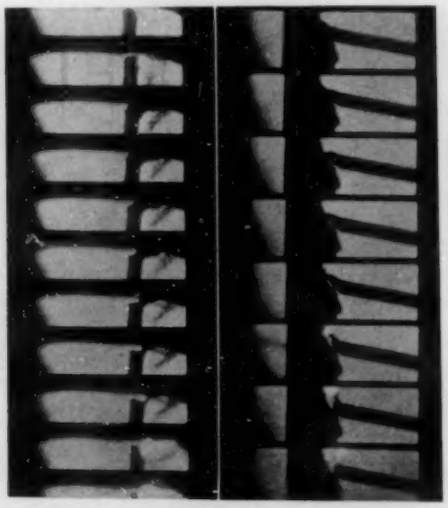


Fig. 8—Picture of Overhead Welding with Time Curve

Fig. 12—Vertical Welding on a Vertical Piece of Work

welding machine was used for the following films, taken according to the last experiences to remove the irregularities of the manual welding. By using a new camera it was possible to reach a retarding of nearly 120 times. That means that an event of one second is produced in two minutes!

For this research a bare wire was systematically melted down with different current strengths. By counting the number of drops in the film and in the oscillogram it was stated that the maximum of the number of drops is only at a certain strength of current. In all cases there was a diminution of the number of drops when the intensity of the current was altered up or down. This intensity of current was the same as the one which is known as favorable in practical experience. The optimal voltage of arc depends naturally on the volt-amp.-diagram of the welding set.

The next film made it necessary to return to the manual welding to be able to fix in pictures also weldings with covered electrodes. Different electrodes were melted down at the negative or positive pole or with alternating current with an intensity of current that experience dictated as the most favorable. These pictures show a principal difference between bare and covered electrodes; while the arc of the bare electrode extinguishes with every drop, observing covered electrodes—especially heavily coated ones—one can see the transition and the arc at the same time, Fig. 5. In this case a drop of pure slag goes over so that there is no short circuit, because the slag is a conductor of second degree. On the other hand, the number of these drops of slag is so little that the rest must go over together with the iron drop. Therefore, one can suppose that every drop is accompanied by a skin of slag protecting liquid iron against the nitrogen and the oxygen of the air. The former published opinion, that a continuous tube of slag grows there, is disproved by these pictures. The slag forms drops like the iron does.

Other important differences one can find between bare and covered electrodes respecting to the number of drops per second and the duration of the single drops. By exact counting of the single pictures—every film has 5000 to 8000 of them—by a counting apparatus built specially for this purpose, Fig. 6, the duration and the number of the drops were obtained, separated in iron and slag drops, and noted down later in the form of Fig. 7. Here the little black boxes mean the duration of the iron drops, the empty ones the duration of the slag drops. The countings prove that the number of drops per second of bare electrodes is great and in covered electrodes is considerably less. As on the other hand a heavily coated electrode melts down a given weight of iron only 30% less than a bare electrode, it proves that many little drops go over from the bare electrode and few big ones from the covered electrode in the same amount of time. This difference is shown very distinctly by the overhead weldings described later on. One can suppose that the single drop of the covered electrode transports more material than the drop of the bare one. As the whole surface of one big drop is smaller than the whole surface of many little drops, making together the weight of this big one, the possibility of entrance of nitrogen and oxygen is greater for a bare electrode. Therefore, one could improve the bare electrodes by a composition which makes possible big single drops. But naturally the danger would hereby not be removed, but only diminished. Contrary to former opinions stating that the actual times of transitions were 50% of the whole welding time, it was proved that the times of transitions are by far less. According to the last measurements one can see that the average is nearly 15% for bare electrodes and nearly 4% for the heavily coated ones. The rest of the time is filled by the lighting arc without transitions of material. The results of the last-discussed pictures are not very exact, because an oscillogram was not taken. The velocity of the film by which these values were found was only read on the tachometer.

To remove this inaccuracy for the next film of over-

Fig. 9—Backdrop

Fig. 10—Hovering Drop

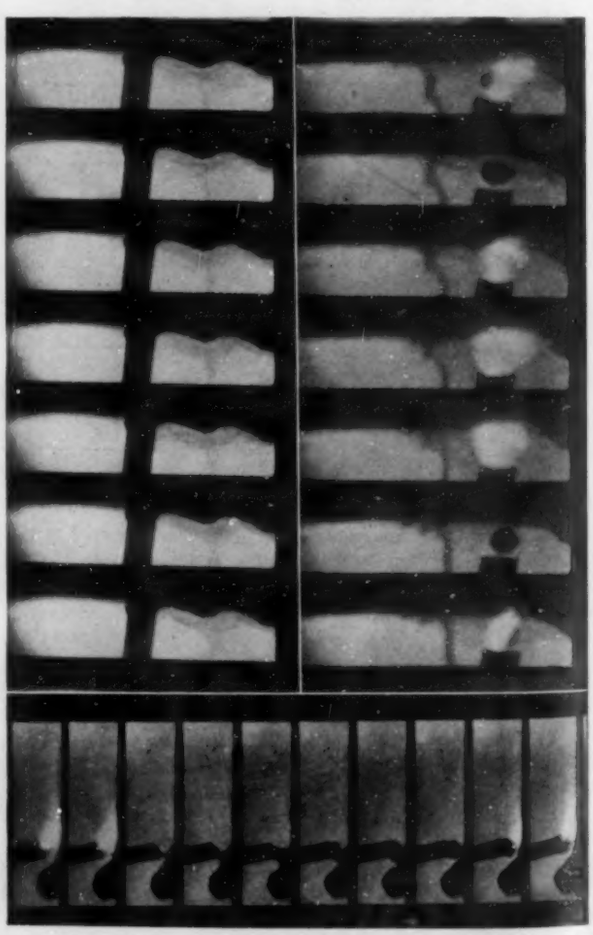


Fig. 11—Horisontal Welding on a Vertical Piece of Work

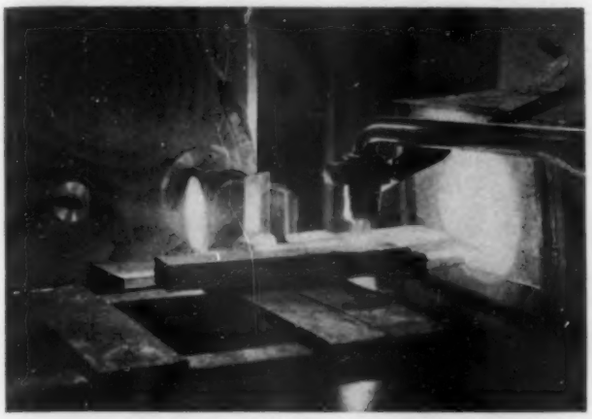


Fig. 13—Apparatus of Inshining Method

head welding a curve of an alternating current of 50 in. was taken on one side of the film at the same time with the exposure, Fig. 8. By this it is possible to state exactly the times of these films on every place up to 1/2000 sec., though the velocity of the film is not constant. Pictures were taken of overhead weldings with bare, slightly coated, heavily coated and covered electrodes at the negative and positive pole as well as an overhead welding of a heavily coated electrode with alternating current. In the pictures of overhead welding one can see another kind of drop, which has to be separated from the real transitions when calculating the times. That is the so-called backdrop. This backdrop, easy to distinguish from the other kinds of drops by its form and time, arises when too much liquid material of the bead flows back to the electrode by gravitation. So it often makes a long short circuit without transporting material upward.

There follows some measurements in these pictures which bring a comparison of a bare electrode at the negative pole and of a covered electrode at the positive pole:

	Bare	Covered
Duration of iron drops	16.5%	2.96%
" of the drops of pure slag	0.0%	1.17%
" of the backdrops	9.27%	0.0%
Total duration of short circuits	25.77%	2.96%
Duration of the longest iron drop	0.06 sec.	0.0014 sec.
" " " shortest " "	0.0017 sec.	0.0008 sec.
Average of the number of iron drops	18/sec.	6/sec.

In discussion of the results there has to be considered the fact that the measurements are single results of a total duration of 3 sec. at most. The absence of the backdrops of the covered electrode is explained by the fact that the arc of a bare electrode must be held still shorter than the covered electrode. Therefore, backdrops arise when the bead sinks down only a little bit.

Considering that the covered electrode melts down only 30% less material than the bare one, the conclusion is that the covered electrode makes bigger drops. A comparison of the time of drops shows that the big drop of the covered electrode goes over in a shorter time, on the average, than the little drop of the bare electrode.

The picture of an overhead welding of a heavily coated electrode with alternating current brought a phenomenon which one can never find in other types of welding. If the top of the electrode is too far away from the piece of work, a single drop occasionally hovers between electrode and bead for a certain time in consequence of the alternating influence of the gravitation and of the welding process, Fig. 10. At first the drop is hurled upward by the welding process, then it is pulled down by gravitation in the moment of the periodical extinguishing of the arc, in the next period it is pushed upward again, etc. On the

Fig. 14—Infra-Red Picture of Gas Cutting

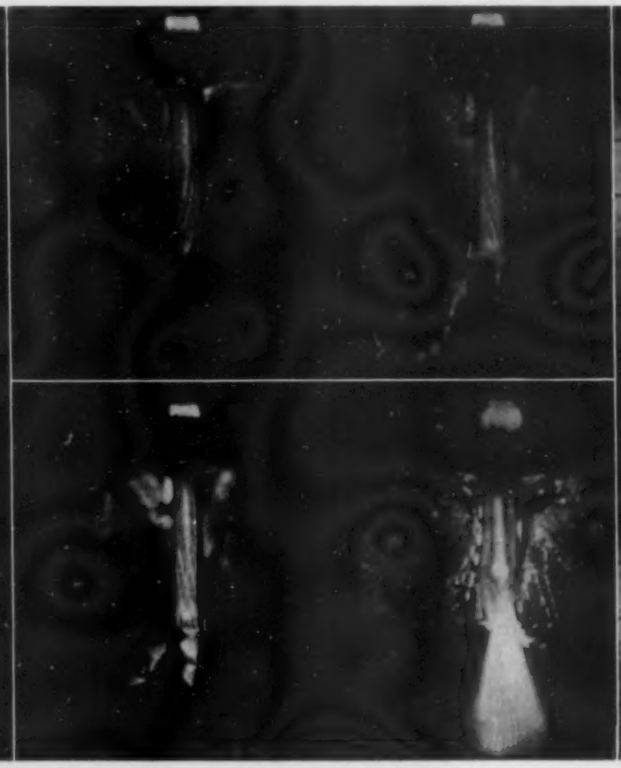


Fig. 16 (Upper)—Movement of Slags. Distance, 1/30 Sec.
Fig. 15 (Lower)—Normal and Double Pressure of the Same Cutting Tip

Fig. 17—Mensuration of the Vertical Velocity of Cutting

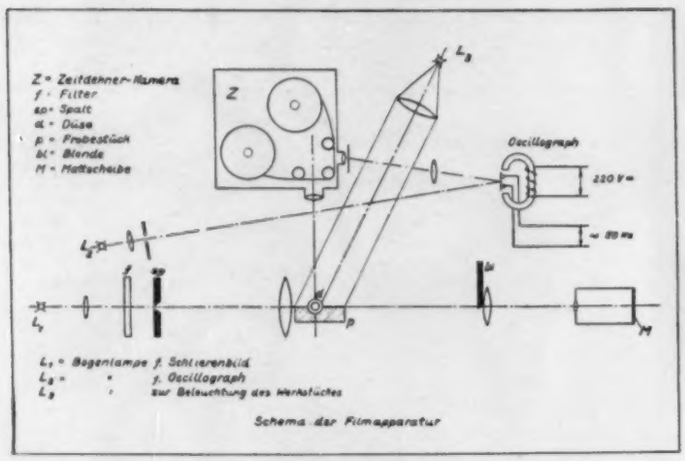


Fig. 18—Scheme of the Apparatus for Measuring the Velocity of Reaction

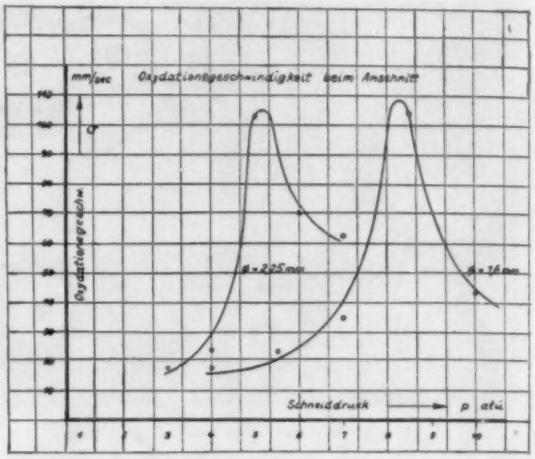


Fig. 19—Curve of the Vertical Velocity of Cutting

whole, there is no important difference concerning the number, kind and duration of the drops between welding with alternating current and direct current with heavily coated electrodes.

Besides these pictures other ones of bare electrodes were taken, showing a vertical welding on a vertical piece of work and a horizontal welding on a vertical piece of work, Figs. 11 and 12.

The time of these weldings did not have any essential differences to weldings with the same electrode in a normal position of work.

Part II. The Events of the Gas Cutting

The successful pictures of the welding arc brought the suggestion to take slow-motion pictures of gas cutting. The first experiments showed that the quantity of light arising by cutting was sufficient to expose the film, but details could not be recognized in the kerf. Here it was necessary to separate the moving slags and the gas beams optically by a special method invented for this purpose by H. v. Conrady, Berlin (inshining method, Fig. 13). The success of this method is that the gas beam absorbs a part of the inshining light but that the little parts of

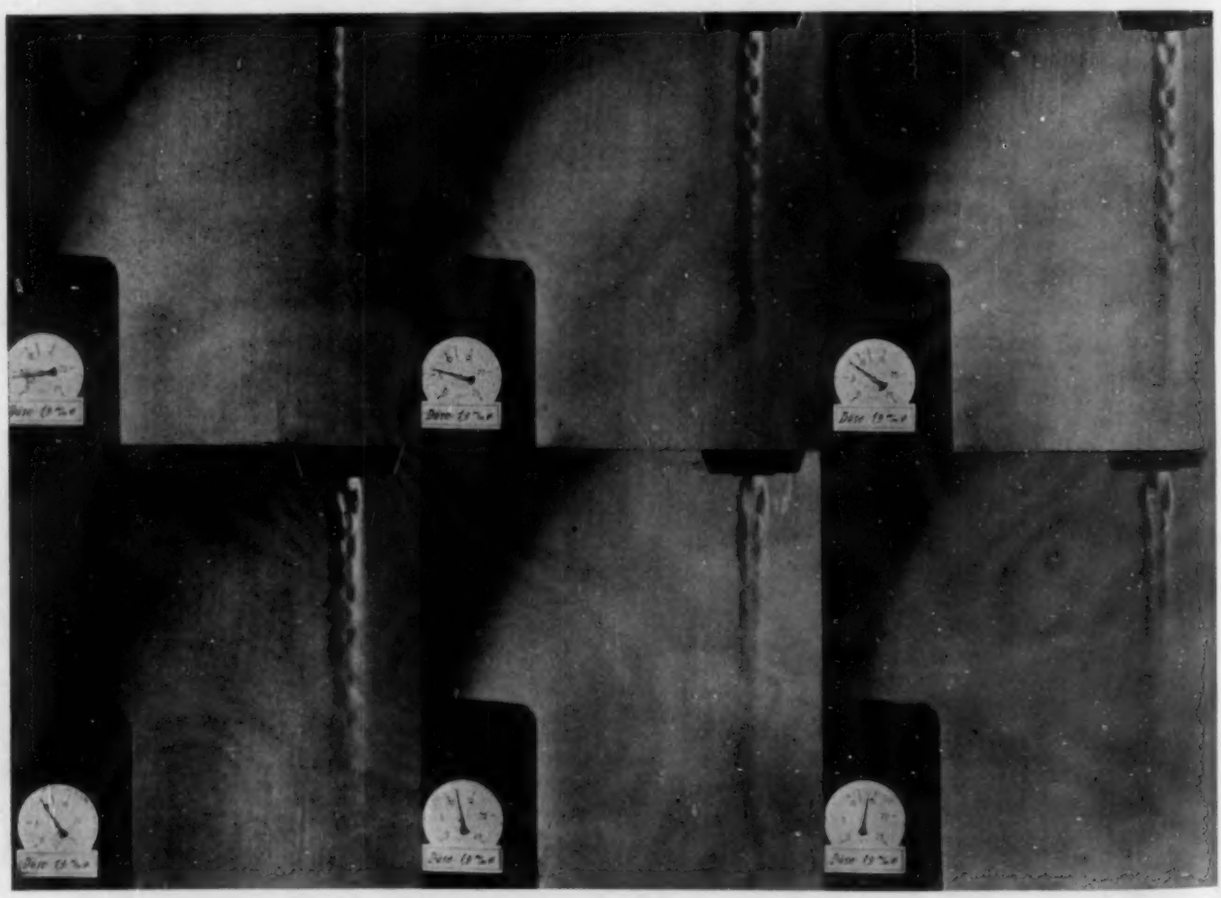


Fig. 20—Forms of Oxygen Beam of Different Pressures

Fig. 21—Copy of the Zones of Pressures on the Surface of the Kerf

Fig. 22—Cutting Beams with Preheating Flame

slag reflect this and so appear lighter. Some experiments with the infra-red sensible Agfa-R-film, mentioned in the first part, showed nothing more than the pictures without inshining, Fig. 14. The light spot visible on all pictures of cutting in the top part is the kernel of the preheating flame below the cutting tip. All other attempts to get a greater clearness by suitable films or filters failed. The inshining method and a normal film brought the final success.

To show a part of cutting as great as possible, it was necessary to take the picture of the cutting process from the front side through the kerf. Hereby the cutting torch has always to be on the same place so that it is clear all the time. For this purpose a cutting machine was altered in such way that the piece of work is transported under the cutting tip toward the lens.

Because one has so used the whole normal size of the film (18 x 24 mm.) one could not take such a great number of single pictures as was reached in the pictures of the welding arc. In spite of this, there were taken 350 pictures per second. For producing such films every single picture of the negative is copied twice on the positive film. Thereby the events are retarded double too.

The pictures made by the inshining method enabled recognition of the following facts: Different currents arise in the beam during the cutting whose kind and origin cannot easily be explained. In all cases one sees that whirls arise in the kerf which become stronger by increasing the pressure of oxygen and which disturb the exactitude of the kerf, Fig. 15. Figure 16 shows a cutting of the same tip with normal pressure by a difference of 1/20 sec. between both the pictures. The movement of the slag parts is not rectilineal but follows certain screw lines, whose turning changes all the time.

The clearness of the pictures, especially in the beginning of cutting, made possible to use the slow-motion pictures fitted with a curve of 50 in. to measure the velocity of the reaction of the burning iron. The velocity of the beam does naturally not correspond to the velocity of the chemical reaction of iron in oxygen, but it is greatly influenced by the velocity of the oxygen beam. Perhaps one could speak of a vertical cutting velocity for this velocity of piercing in contrast to the horizontal cutting velocity.

For these experiments a sheet of 60 mm. was worked smooth on the front side and was divided by lines of 10 mm. distance. Now one can observe in the film the piercing of the oxygen beam, Fig. 17, and with the help of the 50-cycle curve one can measure the velocity between the single lines very exactly.

To get always the same conditions for the experiments the piece of work was placed into the oxygen beam without the preheating flame and its position to the beam was controlled by the method of Toepler mentioned later on, Fig. 18. Former experiments had shown that the vertical velocity of cutting in the beginning depends very strongly on the distance and on the angle of the piece to the beam. The torch was not moved here and only the beginning of cutting was taken. It proves that the maximum vertical velocity of cutting lies at a certain pressure for every cutting tip and that an altering of this pressure upward or downward brings about a slowing down, Fig. 19.

For all these researches it is very important to make visible the form of the oxygen beam. This is only possible by using the method of Toepler, which lets see little alterations of density of a transparent material as light or dark spots in the picture. Figure 20 shows a row of pictures of the pure oxygen beam without the preheating flame made by this method. For controlling, the manometer was taken by a photographic trick at the same time with the oxygen beam to remove confusion and to state later alterations of the pressure. The peculiar form of the beam, which seems to be plaited, refers to standing oscillations in a beam moving with a velocity quicker than the sound. The angle on which the plaited lines cut—the so-called Mach's angle—makes possible to calculate the velocity of the beam in every section.

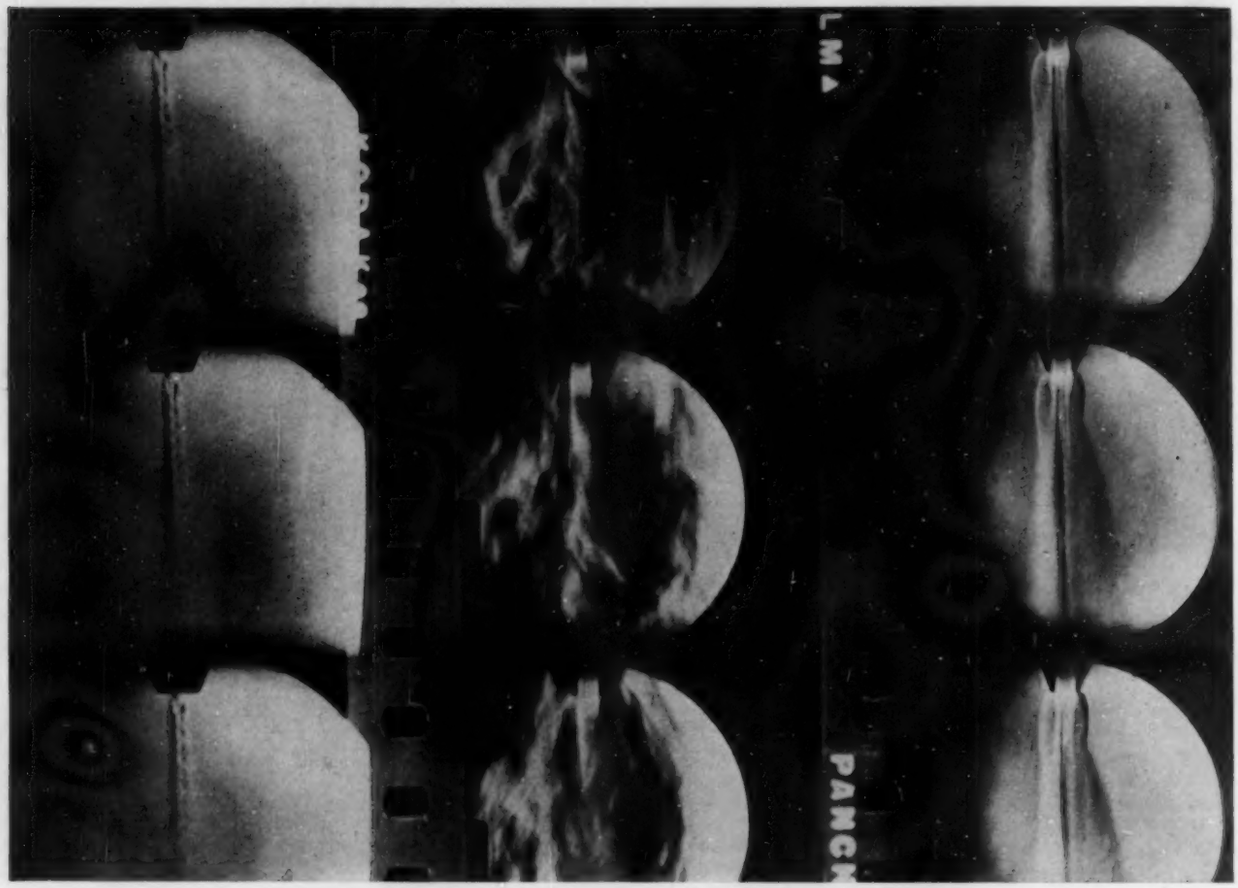


Fig. 23

Pure Oxygen Beam — Backflowing of the Air — Beam and Preheating Flame

Figure 21 shows that the quality of the kerf depends on the form of the beam. The standing zones of different pressures arise in the form of cross lines on the surface of the kerf by the different chemical activities of these sections. On the place which is marked in Fig. 21 by some black points the pressure was suddenly altered during the cutting. In the same way as the distance changes between the zones, the distance also changes between the cross lines.

Some pictures of the oxygen beam with preheating flame are to be seen in Fig. 22. Here the length of the beam is visible far longer through the optical proving influence of the preheating flame. Also one sees that an oxygen beam with high pressure sucks in the preheating flame, which can even be extinguished when pressure is increased.

The moving picture of these events enables us to observe that very clearly. Without the cutting beam the warmed air reflected from the floor covers nearly the whole picture, but when cutting oxygen streams out with pressure, the picture becomes clear by the strong directing of all currents and the beam is visible in the preheating flame. Its longitude and its certain form lie at a certain pressure for every cutting tip. When the pressure is increased or diminished, the visible beam becomes shorter and is by far not so clearly limited.

Some other pictures were taken of the oxygen beam without the preheating flame. One can recognize the arising of Mach's lines and one observes also in these pictures the fact that the beam has its best form by a certain pressure. Therefore, one can state the highest pressures for every form and every diameter of cutting tips by a simple method without cutting any piece. Comparable pictures were also taken of different forms of cutting tips of the same diameter. It proved that the longitude and the clearest form of the beam depend on very little changes of the form of the cutting tips.*

* "Comparing Optical Researches of Cutting Tips," by H. Malz and H. v. Conrady. (Vergleichende optische Untersuchung von Schneiddüsen) *Autogene Metallbearbeitung*, **1932**, Nr. 18. *Acetylen in Wissenschaft und Industrie*, **1932**, Nr. 11, *Forschungsarbeiten auf dem Gebiete des Schweissens und Schneidens mittels Sauerstoff und Acetylen*, **1932**, Nr. 7. Editor: Carl Marhold, Verlagsbuchhandlung, Halle a. S., Germany.

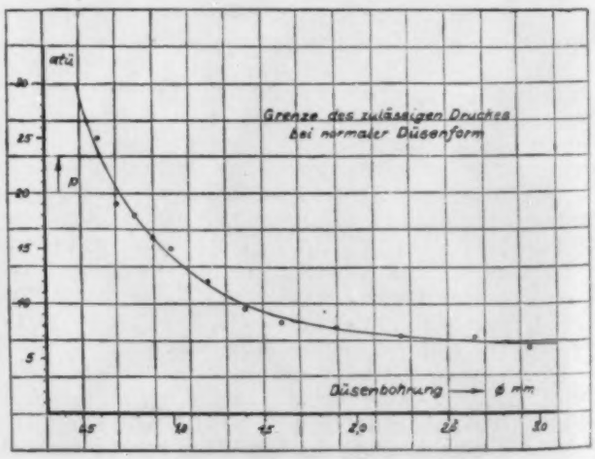


Fig. 24—Curve of Highest Pressures

Arc Welding Bridges in Great Britain

By **R. M. GOODERHAM**

✦Mr. Gooderham is London Representative of The Lincoln Electric Company.

WHILE welding has made rapid progress in the British Isles in the last few years, its use has been somewhat limited to certain industries. Among those where welding is gaining favor but is still comparatively new, is the structural welding field.

Less than two years ago the first arc-welded bridge in Great Britain was built near Houston, Renfrewshire, Scotland by Sir William Arrol and Company, Ltd. This small plate girder bridge has a span of 62 ft. 6 in. and is designed for a load of 20 tons. The distance from center to center of the girders is 16 ft. 3 in.

The construction of the bridge is very simple. The girders were built up of a 15-in. by $1^1/_2$-in. bottom plate, a 53-in. by $^3/_8$-in. web plate and a cover flange channel 15 in. by 4 in. The web plate is continuously welded to the bottom plate and to the top flange channel. At approximately 4-ft. intervals, 6-in. by $^1/_2$-in. stiffeners are welded to the web plates with intermittent welds, as shown in Fig. 1. Above each of the seven cross-beams 6-in. by 3-in. by $^3/_8$-in. tees are bolted to the top girder flange and extend to the end of the cross-beam, as shown in Figs. 1 and 2.

Due to the flood level of the river and the level of the adjacent roadway, it was necessary to suspend the cross-beams in order to keep the bottom flange of the main girders clear of the river and maintain the roadway level.

This bridge was welded entirely by the shielded arc process using covered electrodes supplied by our Company.

Following and even before the construction of this bridge, there was not a little work done in the British Isles on the strengthening and reconditioning of weakened bridges. The London and North Eastern Railway has been a leader in this development and has successfully strengthened by welding many weak bridges which would otherwise have had to be replaced. Most of this work consists in adding metal to weak girders or trough floors or cutting out corroded plates and welding in new ones.

As this is written, the first important all-welded highway bridge in the Kingdom is nearing completion. This is a bridge over the London and North Eastern Railway tracks at Middlesbrough.

The bridge as originally planned called for only one span and this was designed for riveting. Later it was decided, owing to insecure foundations, to increase this span to three so as to take the weight farther away from the railway tracks which pass underneath. A preliminary riveted design for a three-span structure was produced, but the designer, who had previously built a small welded bridge over a canal, saw obvious advantages for welded design in this particular project. By taking advantage of the unit construction of the welded design the

Fig. 2—The First Arc-Welded Bridge in Great Britain, Erected by Sir William Arrol and Company, Ltd., in Scotland

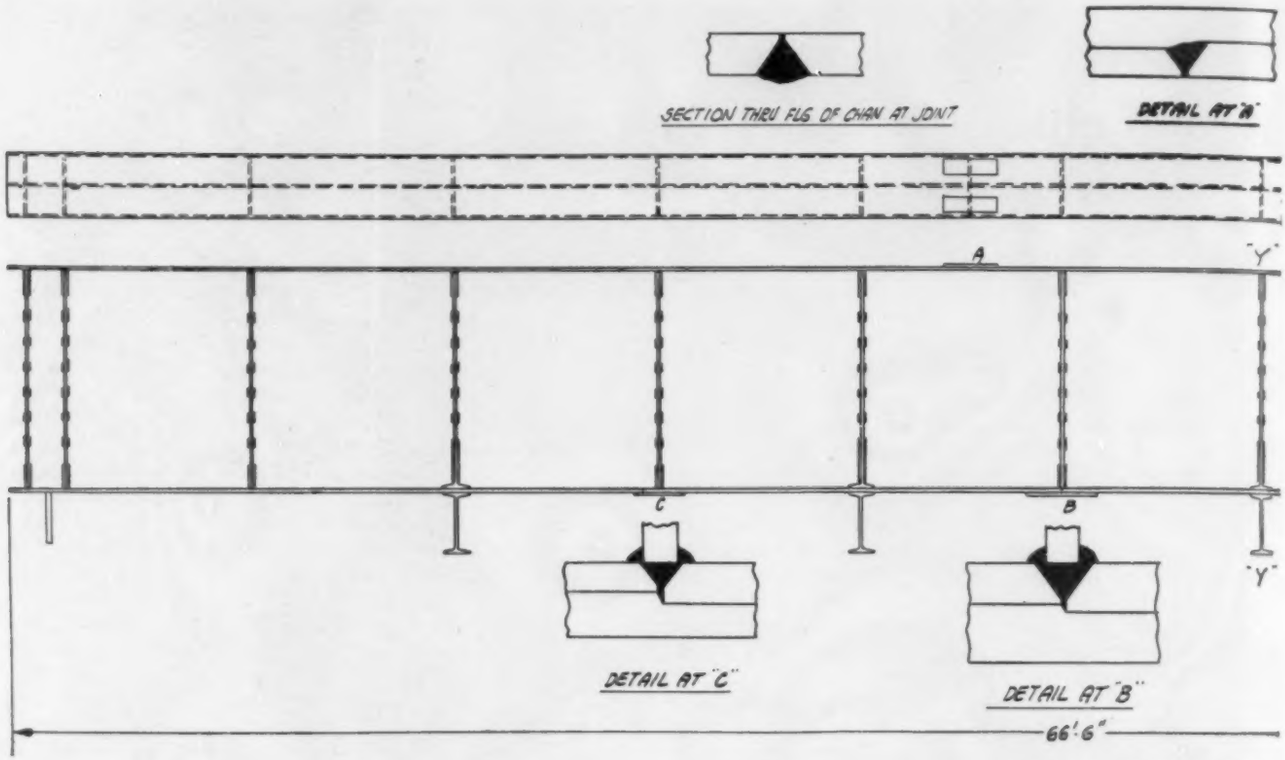


Fig. 1—Elevation of Bridge

weight was distributed equally over the piers and the end embankments.

The welded design permitted the main beam of the span to be reduced from a minimum of some 5 ft. in the riveted design to 3 ft. 6 in. in the welded design. This, of course, considerably reduced the weight of the bridge. The total estimated weight saving is approximately 20%.

Various considerations, including the desirability of maintaining the road level, difficulty of securing satisfactory foundations and the necessity to avoid disturbance to the railway tracks, led to the adoption of the profile of the bridge, as shown in Fig. 3.

The deck is 216 ft. long with a 38-ft. roadway. Footpaths are provided varying in width from 8 ft. 9 in. to 10 ft. 9 in. This variation is accounted for by the fact that the center line of the approach is on a curve and the parapets of the bridge extend straight on the outer girders.

The center span, the longest one, is 64 ft. in length. In each of the spans the deck is carried on 9 longitudinal girders, one under each parapet and seven under the roadway, evenly spaced from curb to curb. With the elimination of flange angles in the plate web girder sections there was considerable labor saved in the difficult work of bending angles to the various curves of the profile.

The longitudinal girders under the roadway are built up of webs, to which the top and bottom flanges are welded. Over the two central supports, and throughout the center slung span, the webs are $^3/_4$ in. thick. Elsewhere the webs are $^5/_8$ in. thick. The top flanges are 12 in. wide, the bottom flanges 13 in. wide. The welding of the flanges to the webs is in continuous seams. The stanchion legs are made up of a web $^3/_4$ in. thick for central stanchions and $^5/_8$ in. thick for the outer stanchions. To each web are welded plates 13 in. wide, forming a section similar to the girders. The girders and stanchions are made continuous by the welding of their webs and flanges.

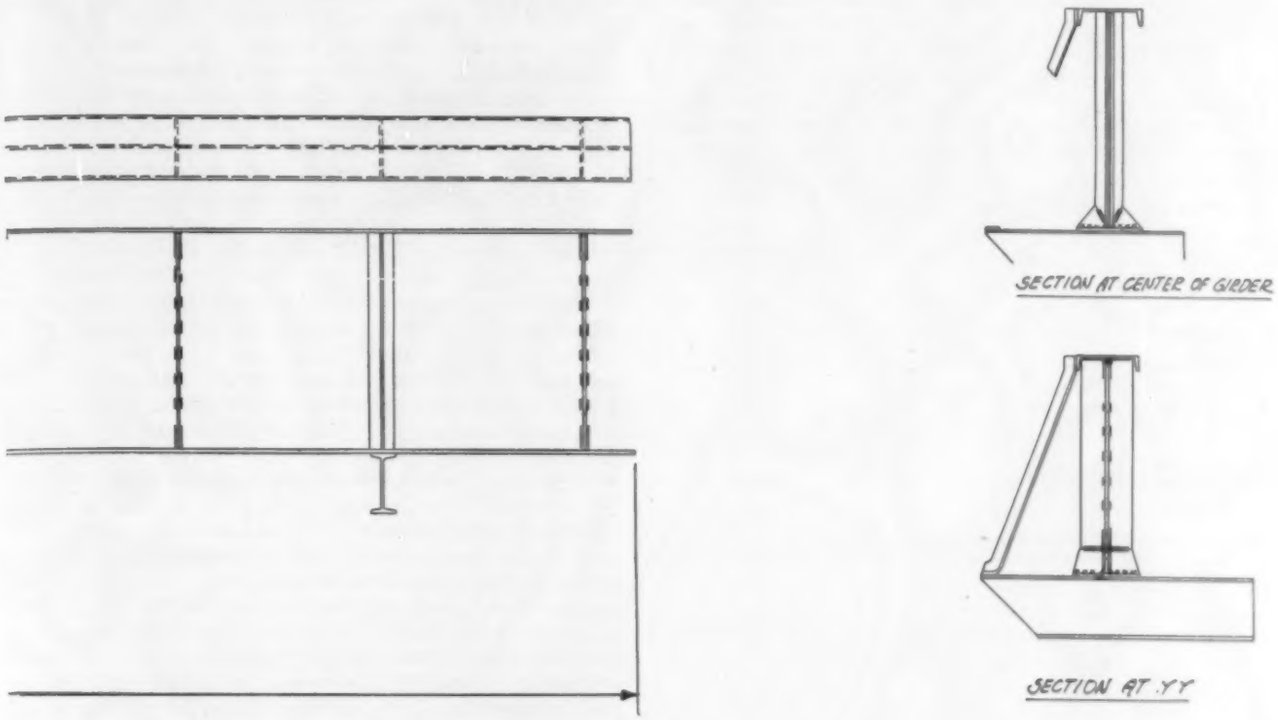
The longitudinal face girders supporting the footpaths and parapets, together with their supporting stanchion legs, are built up of sections similar to those under the roadway.

In the construction of this bridge the field welding was kept at a minimum, most of the welding being done in the shop where closer supervision and more favorable conditions insured better construction. The only field splice on the girders is that at the junction of the girders and the stanchion legs. Overhead welds were eliminated as far as possible.

Stiffeners were welded to the webs and inner faces of the flange plates of the girders at 4-ft. intervals. On the face girders stiffeners occur only on the inside. Two types of intergirder bracings are utilized. Over the columns these bracings take the form of diaphragms $^3/_4$ in. thick with 6-in. by $^1/_2$-in. flange plates top and bottom. The diaphragm plates are welded to the webs and inner faces of the girder flanges and the top and bottom plates are welded to the edges of the girder flanges. The stiffening effect is increased by having knee braces extending from the under sides of the braces and welded to the webs of the stanchion legs.

The second type of bracing, of which there are 11 sets distributed along the girders, consists of crossed diagonal tees placed back to back. The ends of these tees are shaped for welding to the girder stiffeners. These bracings are completed with a horizontal tee at the level of the bottom flanges of the girders and welded to the flanges.

The roadway will have a trough floor built of standard sections and, instead of adjacent troughs having lapped joints, it has been adapted to rest evenly on the girder with edges of the adjacent trough plates butting one another. Over the girders holes countersunk on the upper side have been drilled out of the troughing, making it possible to plug weld the troughing to the girders.



Built Near Houston, Scotland

Expansion joints have been designed for the deck—one for each abutment and one over the expansion joint left in the longitudinal girders. These take the form of pairs of ballast girders, one sitting on each side of the joint. The top cover plate is attached to one ballast girder. This plate is free to slide on the other ballast girder.

Contractors for this bridge are the Dorman, Long & Co. Ltd., with Mott, Hay & Anderson as consulting engineers.

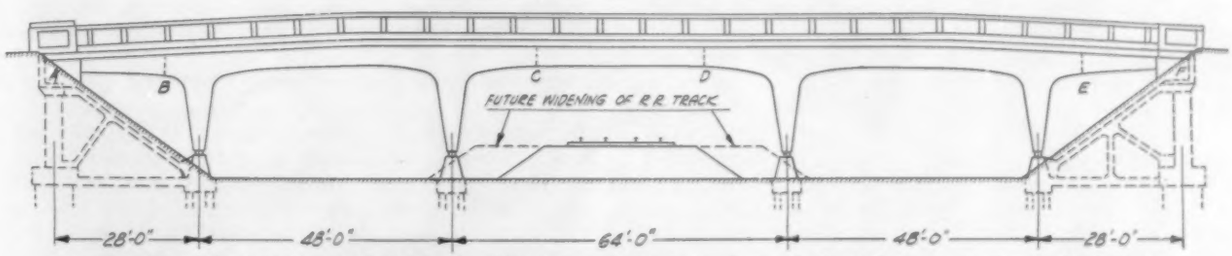


Fig. 3—Profile of All-Welded Highway Bridge Near Middlesbrough, England. Letters Indicate Joints in the Longitudinal Girders

A Way to Remove Last Layer of Welding

By C. J. HOLSLAG

†Mr. Holslag is President of the Electric Arc Cutting & Welding Co.

IT IS known that layer annealing improves the multiple layer weld. Every layer of weld changes the grain structure of the deposit of the layer beneath it to a better structure, that is, to a better steel, but the joker is you have a deposit left every time that is not good grain structure.

A new electrode has been developed called the Normalizing Electrode to handle the last layer. Without adding metal, the proper refining action is obtained very rapidly and at very little cost. This electrode also smooths over the inequalities of the weld and makes the weld have a good appearance. It is now possible to make the last layer of the heavy oil still, penstock, air receiver, boiler and similar work just as good as the rest of the metal whereas, heretofore, it was necessary to leave the outer deposits of very poor metal due to the undesirability of machining off the added layer. This rod which entirely consumes itself can be used to anneal a line across metal for bending, breaking or wherever grain structure change is desired. This electrode machines itself clear and like the Irishman's remedy for train wrecks—there is no last car.

The electrode is made of reasonable high-carbon steel, that is, steel with a low melting point. There is a fibrous covering over this electrode with manganese dioxide and potassium perchloride over this consisting of a

non-hydroscropic magnesium silicate which keeps the inner covering from losing its properties until an arc is struck, at which time the oxidizing chemicals burn up the rod leaving only the magnesium silicate slag over the deposited metal.

In vertical welding or overhead, it is now impossible, practically, to obtain the ductility and good results of hot welding but with this electrode it is not only practical but especially feasible for vertical and overhead work. Single course welds and single bead work can now be made of the best grain refinement, whereas heretofore it has been impossible on bridges, tanks and such construction to obtain these best arc-welded results.

Another desirable action accomplished by this action is a glazed covering which allows painting, red leading, annealing or the like over the weld, whereas previously the leaking gas from the original weld deposit causes such a covering to chip, blister and crack.

Galvanized Piping

By **T. W. GREENE**

†Mr. Greene is a member of the Development Section of the Engineering Department of The Linde Air Products Co.

A Frank Discussion of the Merits of Welded Galvanized Iron and Steel Pipe

EXPERIENCE points to the fact that welding galvanized pipe, whether iron or steel, does not affect the corrosion resistance or strength of the pipe itself, and the question of the use of either steel welding rod or bronze welding rod is not, therefore, a serious consideration when endeavoring to determine the best type of joint.

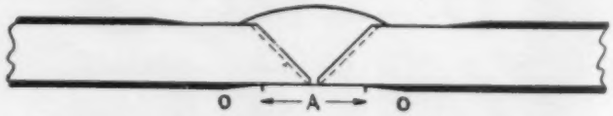
Since the galvanized coating on pipe is simply a surface condition, there can obviously be certainty regarding the high strength of a welded joint in galvanized piping. That welded piping of any kind is so extensively used today and is, in fact, generally accepted by most engineers and contractors as being the ideal joint for any piping installation, points to the fact that strength of a line is increased when welding is used. Steel welded joints when made with a high test steel welding rod develop better strength than the actual strength of the base metal in the pipe itself. Bronze-welding of steel and cast-iron pipe, where this is indicated, will develop strength in steel pipe up to 55,000 lb. per sq. in., which is much greater than the usual strength of cast iron which ranges from 20,000 to 30,000 lb. per sq. in. and, in the case of steel, comes so close to the strength of ordinary mild steel that this factor is important only where particularly high strength joints are necessary.

The question of welding galvanized piping, particularly bronze-welding from the standpoint of corrosion, has arisen frequently. In fact, this question has been of such a controversial nature that it is desirable to review experiences and practical every-day facts in regard to this subject, which unfortunately are often forgotten in its consideration.

Both steel welding and bronze-welding of galvanized piping have been practiced for many years, and to, date, there has been no evidence or complaint of accelerated corrosion at the joint as the result of welding. The whole facts and conclusive deductions will probably not be established in the lifetime of any living investigator or in the span of years of any engineer or person concerned with this subject, as obsolescence and replacement practically always are more important factors than the life of the welded joint or piping system. However, sufficient experience and consideration of practical facts point to one conservative conclusion; namely, that with the exception of piping exposed to highly corrosive mediums, as dilute acid or alkaline solutions, no appreciable accelerated corrosion will occur at the joint as compared to the rest of the pipe when welded either with steel or bronze-welding rod, or whether galvanized or ungalvanized.

Unfortunately the phenomena of *electrolysis* is occasionally confused in a consideration of the welding of galvanized steel pipe, particularly bronze-welding. Electrolysis is generally considered as corrosion resulting from stray currents, and shows itself principally as excessive deterioration where the current leaves the pipe. Welding is not a factor except that it improves the condition at the individual joints because the welded joint is an excellent conductor, localizing the corrosive effect only at the point where the current ultimately leaves the line which may not be a joint. Corrective methods for this are by grounding the pipe, a method well established through experience, or the more costly method of trial and error.

On the other hand, *galvanic* corrosion, resulting from potential difference of dissimilar metals, has been the



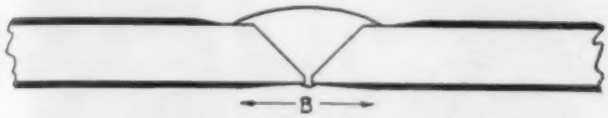
Cross Section of Wall of Galvanized Pipe Showing a Fusion Weld

principal factor to cause prejudice against the use of bronze-welding. Off-hand consideration of this effect would at first glance point to corrosion at the joint, where dissimilar metals such as a bronze-welded joint on steel or cast iron are used, but experience establishes the fact that accelerated corrosion does not occur. This has led, in recent years, to eminent authorities on the subject of corrosion altering their conception and theory of this phenomenon. A few common experiences may be briefly reviewed as follows:

1. Examination of the battleship *Maine*, containing as it did numerous examples of contact of non-ferrous metals with cast iron and steel and subject for years to salt water action, showed no evidence of accelerated corrosion of these points of contact.

2. Bronze-welded cast iron and steel pipe has been used for years subject to both external soil and internal corrosion and has led to no complaint of deterioration of the joint. In the case of cast iron, many lines have been laid in various sections of the country, in service for over 8 to 9 years, in which the bronze-welded joints have shown no signs of corrosion. In fact, examination by engineers of gas companies vitally concerned with the subject of corrosion has shown that while a protective coating applied at the joint in anticipation of trouble had entirely disappeared, there was no evidence of greater corrosion at the joint than anywhere else throughout the body of the pipe.

3. A large company that has been manufacturing



Cross Section of Wall of Galvanized Pipe Showing Bronze-Weld

acetylene generating units for house lighting for many years, has been using bronze-welding for joining galvanized steel shells. Thus, literally thousands of units are buried throughout the country under varying conditions, subject internally to water of varying corrosive intensity and soil conditions externally. No complaints have even been received to warrant any change in the method of construction.

4. Brass and bronze seats and parts in valves and other fittings, brass and copper tubing in cast iron and steel condensers, as well as other examples in innumerable kinds of mechanical equipment, conclusively illustrate that contacts of dissimilar metals do not cause serious corrosion.

5. Practical research by members of the American Petroleum Institute and the American Gas Association, in which bronze-welded examples of ferrous metals have been buried throughout the country, has shown no evidence of deterioration because of the dissimilar metals. These investigations, together with many other common facts, some of which have already been enumerated, have, as previously stated, modified the theory of corrosion.

An important factor that is not generally considered when studying the welding of galvanized pipe is the comparison of the effect of welding with threading. Threading, of necessity, has been accepted as satisfactory. Often the galvanized pipe has to be cut and threaded for which, of course, the galvanizing is removed. Moreover, this occurs at the point where the wall thickness is materially reduced by the thread. In contrast, welding, which does not remove any greater amount of galvanizing, does not reduce the wall thickness to shorten the life of the pipe.

In addition to giving full wall thickness at the joint, welding actually increases the resistance of the pipe against corrosion in the zone where the galvanizing is melted. Millions of welded steel joints have definitely proved that the weld and adjacent metal are not subject to any greater deterioration than the rest of the pipe. In fact, experience of engineers, who have taken the the trouble to investigate, has shown that, on the contrary, the weld and adjacent metal are more resistant to corrosion. Lines which have deteriorated in a very few years through pitting, which is the important effect of corrosive deterioration, after standing an examination have been found to be practically free of pitting and corrosion at and adjacent to the welded joint. Without going into the theory of this corrosive resistance of the joint, which probably is the result of formation of a highly resistant oxide coating formed in the heating of the joint, this experience can be accepted as definite proof that even though galvanizing is removed to some extent in welding, the exposed metal is more highly resistant to corrosion than that for threaded joints, since at the latter the area is not only robbed of the protective coating of the galvanizing, but is also reduced in wall thickness.

It would be well at this point to review what actually happens on a pipe, galvanized, when either fusion welding, including welding, or bronze-welding is applied. In considering the effect of welding on galvanizing, it must be assumed that welders of reasonably good ability, who realize that, in general, all welding should be done with the minimum amount of heat consistent with good fusion or adherence of the weld deposit, are being employed.

In applying neutral flame fusion welding to galvanized pipe, using a steel welding rod, approximately the portion of the inside pipe wall marked "*A*" in the sketch will become very hot due to the direct application of the flame on the reduced thickness of the beveled ends. In this type of welding where considerable portions of the beveled ends would be melted and fused into the weld metal, it is safe to say that galvanizing is completely removed from the portion *A* on the inside of the pipe, as well as for a distance equal to or even greater than $^1/_2$ *A* beyond the limits of the weld on the outside of the pipe wall. More galvanizing is removed from the outside because of the more direct contact with the welding flame. On the inside beyond the width *A* galvanizing is gradually increased to the original thickness at such a point as *O* where the heat has not been intense enough to volatilize the zinc.

A steel fusion weld made by the slightly carbonizing flame would produce a considerably narrowed band of zinc volatilization. The advantages of greater speed and less heat involved in the fusion of the merest surface skin of the bevels are particularly important in reducing the width of the band *A*.

However, in making a bronze-weld, where the surfaces of bevels forming the vee are always well below the fusion temperature, the minimum intensity and duration of heat will have still less effect on the coating.

The distance *B* in the second sketch approximately represents the width of a band around the inside of the pipe where the galvanizing will be at all affected. The effect will be negligible near the edges of this band with a gradual thinning of the galvanizing as the center of the weld is approached. For a short distance, perhaps $^1/_8$ or $^1/_{16}$ in., on each side of the center of the band the galvanizing may be completely removed from the abutting pipe ends. In many instances, however, a thin film of bronze spreads around the inside surface of the pipe much as solder will spread automatically on a properly tinned surface when the heat is right. This spread of bronze around the lower edge of the thin portions forming the vee protects the edges somewhat even though the galvanizing may be completely removed for a small distance back from the ends.

In bronze-welding the lower heat joint and the character of the metal deposited all combine to give maximum protection from corrosion. No instances are known of premature failure of galvanized piping due to early corrosion of the welded joints.

Where discoloration of the water or other material carried by the line is the important factor, it can be noted that the unprotected area subject to corrosion on the inside of the welded pipe joint will be considerably less than the exposed area of cut and possibly reamed ends of the pipe and the unoccupied fitting threads found in the screwed joint. Furthermore, as there are no pockets at the welded joint, corrosion under alternate wet and dry operation is much less rapid where the joints are welded than where they are screwed.

All things considered there seems to be every advantage in favor of the welded joint for galvanized pipe. With a bronze available which will permit welds of better than 55,000 lb. per sq. in. strength there is no reason to question the bronze-welded joint structurally, at least for the more ordinary services for which galvanized pipe is used. Oxyacetylene fusion-welded joints are already well known for the high strength which they present.

It may be concluded that experience points to the fact that corrosion of welded galvanized pipe is not a matter for consideration. It may be welded with either steel or bronze welding rods, the choice methods being principally a matter of economics and appearance.

Heavy Welding

By H. L. R. WHITNEY

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DURING the time allotted to me to present this paper, it is impossible to cover the whole subject of heavy welding. I am, therefore, confining myself principally to the welding of large heavy-walled pressure vessels rather than to the welding of heavy structural shapes, engine bases, etc.

In all heavy welding the effect of mass must be taken into consideration, not only on design but on forming, welding and stress-relieving. The knowledge obtained primarily in the petroleum cracking industry on the behavior of heavy-walled pressure vessels has led to steady improvement in design, affecting the shape of heads, the reinforcement of openings and the selection of proper materials, all of which are pretty well covered by the present A. S. M. E. Code for Unfired Pressure Vessels and various A. S. T. M. Specifications for materials. The joint Committee of the A. S. M. E. and the American Petroleum Institute are working on a combined Code and it is my fondest hope that we will some day have one code which covers all pressure vessels in all States of the Union and for all branches of the Federal Government, Interstate Commerce Commission and everyone else.

Materials

All of the defects found in smaller thinner plate, usually made from smaller ingots, are liable to be of a much more serious nature in large heavy plates made from big ingots.

Segregation is often so serious in rimmed steel that not only must the ingot be heavily cropped but the slab or plate itself must be cropped before the resultant plate is of sufficiently uniform analysis and structure to be used.

The use of killed steel overcomes to a very great extent the problem of segregation, but then we have the problem of a secondary pipe in the ingot which, if present, would result in a serious lamination in the plate.

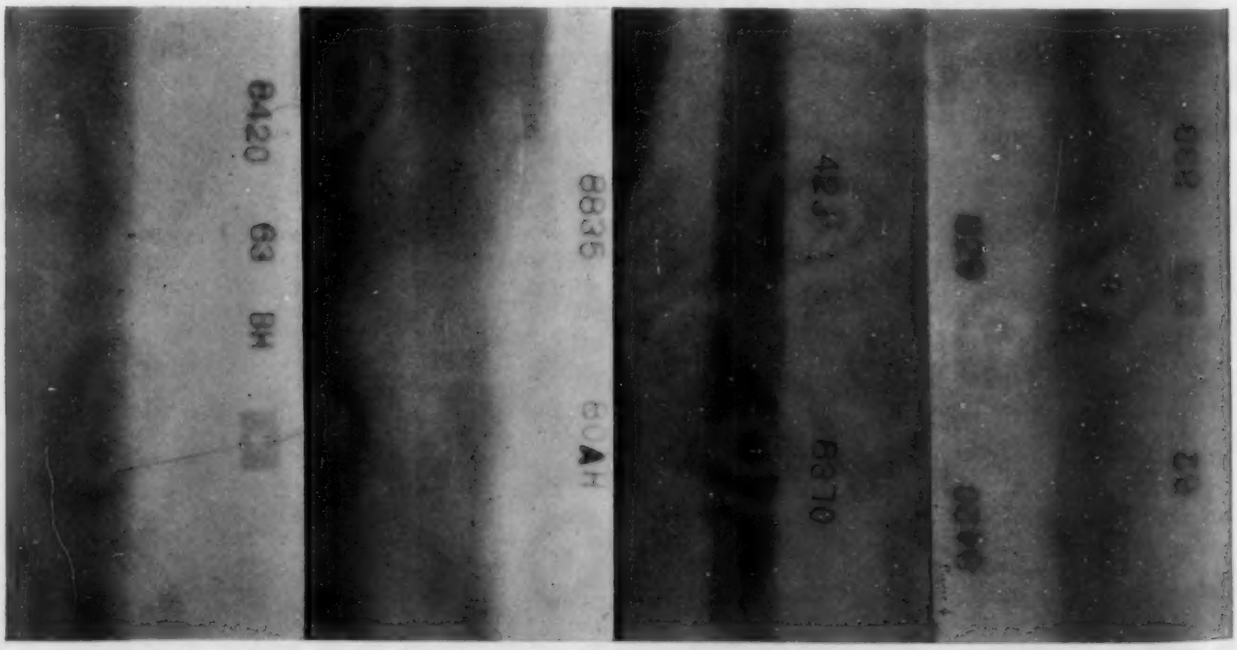
Chemical analyses and physical tests of samples taken from the plate give us a definite answer to the questions of segregation and physical properties, yet there is nothing but experience to tell one where to look for indications of laminations and scabs. Going over the edge of the plate with a torch shows much to the experienced inspector and heating the entire plate will often reveal laminations as well as scabs. However, these defects may not be revealed until hot bending is well under way and sometimes not until the vessel is tested. The best advice I can give is to pay the price and purchase such material only from the few mills qualified to make it and then inspect most carefully.

Fabrication

Forming.—All heavy plate should be stress-relieved before forming, and hot forming is most desirable even where equipment is sufficiently heavy to cold form. In other words, the material should be in as benign a condition as possible before welding.

Welding.—When the actual welding of heavy materials begins then is when the real troubles begin. The parts to be welded must be of even thickness and most accurately set up and held. In cold weather these parts must be preheated to a uniform temperature and in many cases this preheating should be regular practice. Proper design of welding groove, selection of a proper rod, the rate of feed and speed, the accurate control of voltage and amperage, all become increasingly important as the thickness increases.

Only welders who have qualified, not only on test pieces, but whose welding on actual heavy work has been radiographed, should be used. The men removing the slag from each bead as it is deposited must be



Figs. 1 to 4—Radiographs of Good and Bad Welds

Fig. 5—Evaporator Tower—12′ 0″ ID x 2⁷/₁₆″ to 3¼″ Thick x 48′ 5⁵/₁₆″ Long. Plate Construction. Weight, 285,340 Lb.

experts and able to detect immediately lack of fusion and surface cracks. If it is necessary to stop the work that part of the weld already made must be stress-relieved before additional material is laid in, otherwise cracks will develop. The welding must go on continuously if intermediate stress-relieving is to be avoided.

Radiographing

Radiography is the only means yet developed which tells what must be known of a weld and even with radiography wide experience is necessary to properly interpret the radiograph. Wide experience was necessary in the war to properly interpret airplane photographs, and many times accurate interpretation of shadows, etc., was not made until the terrain photographed was captured. Shell-holes were easily interpreted. So is it true in the radiographic examination of welds; what certain shadows or changes in density really indicate can only be determined by exploration, such as chipping; simple porosity is easy of interpretation and is the least of our worries.

Figure 1 is an X-ograph of a portion of a circular weld in a vessel 3½ in. thick made up from seamless cylinders. This X-ograph was passed by the inspector and has since been passed by more than one expert; however, the responsible man in the Kellogg Factory was not satisfied, and chipping where the slight shadow started an unfused area about 10 in. long was found.

Figure 2 is an X-ograph of an obviously bad weld joining plates 2¼ in. thick.

Figure 3 is an X-ograph of a good longitudinal weld joining plates ⅞ in. thick.

Figure 4 is an X-ograph of a good circumferential weld joining seamless cylinders 3⅞ in. thick.

Figures 5, 6 and 7 illustrate some large heavy-walled vessels, the welds in all of which were radiographed.

Some men of experience contend that the removal of the overlying beads is necessary to the proper interpretation of a radiograph, and many lay great stress on porosity. My experience based on X-ographs taken of a great many hundreds of feet of both thick and thin welds is that the lighter area, due to the weld being thicker than the base metal, marks the weld, and one's eyes concentrate automatically on that area; and that defects or indications of defects are more easily detected with the overlying beads left on than when removed.

Radiographs improperly developed, focused or exposed, particularly over-exposed, are valueless. In fact, there are many ways of fooling the uninitiated in the making of radiographs, just as there are in determining the yield point by the drop of the beam.

So also can the honest but inexperienced fabricator be led to discarding safe welds which show porosity and to accepting dangerous welds full of unfused areas and cracks.

The difference in cost between welds which are radiographed and welds which are not is not so much in the first cost of these welds, but in the cost of repairing what the honestly taken radiograph reveals. The ever-increasing tendency toward lower prices is bringing out rods of higher speed and tempting the fabricator to increase his current and weld at speeds even higher than those recommended by the rod manufacturers. The result is extensive unfused areas, cracks and slag inclusions which may, or may not, be accompanied by excessive porosity. The fact that a welder can produce beautiful samples means nothing, and no inspector, unless he has complete control of the fabricator's entire procedure, can honestly state that a product is welded by the same technique as the samples. It is, therefore, my firm opinion, particularly under present business conditions, that any regulatory body granting high efficiencies for welds not radiographed or permitting the use of unradiographed welded vessels where there is a hazard, is negligent in its duty.

Test Specimens.—Representative test specimens of welds are of great importance as a weld having highly improper physical characteristics may pass a radiographic examination almost perfectly. The only truly representative test specimens are those cut from finished parts of the actual structure (such as crop ends or rounds cut through the girth welds for the installation of nozzles). Such specimens have been subjected to the actual stresses set up in fabrication. This applies particularly to the welding of heavy sections.

Stress-Relieving.—As to stress-relieving, my twenty years' experience teaches me that only large diameter welded vessels three-quarters of an inch or less in thickness are really safe unless stress-relieved, except for non-hazardous, constant pressure, low temperature service. This is a broad statement but I have been inside of many non-stress-relieved hammer welded vessels in which the stress concentration due to welding is much less than in fusion welding, and I have been inside of a few non-stress-relieved fusion welded vessels. Most of these vessels were operating with more or less corrosive contents and the speed of corrosion in the over-stressed parts was as apparent as a chalk mark on a blackboard. I can also show you vessels of seamless forged, fusion welded and hammer welded construction badly cracked just from the welding on of small nozzles in the field. The heavier the welded structure the more important is stress-relieving and the more important is the procedure of stress-relieving. A proper furnace for stress-relieving must be of the car type and muffled so there is no impingement of the flame on the contents. The furnace must be under exact control. Thermocouples should be located along the furnace at both top and bottom and connected to recording instruments. Thermocouples must also be laid on or attached to various parts of the structure to ensure that all parts of the structure are being evenly brought up to temperature at a proper

Fig. 6—Evaporator Tower—10′ 6″ ID x 2¹¹/₁₆″ and 3⁷/₁₆″ Thick x 55′ 10″ Overall. Seamless Cylinder Construction. Shipping Weight, 322,300 Lb.

Fig. 7—Kellogg Seamless Cylinder "Masterweld" Soaking Drum, 10' 0" ID x 3" Thick x 69' 6" Long. Weight, 309,200 Lb.

rate, and held at an even temperature (of from 1100 to 1200 deg. Fahr.) for a sufficient length of time to bring about complete repose of the entire structure. After the fires are turned off both the furnace and contents approach a more and more even temperature, however, the furnace must be designed so that there are no draughts through it after the fires have been turned off. The structure should not be removed from the furnace until black and it should be so placed that it cools slowly and evenly.

Nozzle Reinforcement.—Wherever possible the reinforcement of nozzles or openings should be so designed that the base weld which transmits the load into the reinforcing pad can be radiographed. Where it is not possible to radiograph the base welds, and where the opening is reinforced, a small hole should be drilled through the pad and a hydrostatic test applied. When 24-in. diameter openings and total thicknesses of shell and pad upward of 8 in. are involved we have a welding problem of the first magnitude. Therefore, only the most experienced welders should be used on this work.

Effect of Hydrostatic Test Requirements on Reinforcement

Under the present requirements of the A. S. M. E. Unfired Pressure Vessel Code (Par. U-77) all welded vessels must be tested to twice the pressure at which their shells would be rated at atmospheric temperature. Accordingly, using the required factor of safety of 5 and the allowable weld efficiency of only 90 per cent for Class 1 vessels, we have a permissible working stress of 9900 lb. per sq. in. in 55,000-lb. plate, and a test stress of 19,800 lb.

It is recommended that the factor of safety be reduced to 4 and the efficiency of Class 1 welds raised to 95 per cent. If we apply this recommended factor of safety and increased efficiency in the Boiler Code or Common formula and test the vessel to only one and one-half times the rated pressure at atmospheric temperature, we would have an allowable working stress of 13,000 lb. per sq. in. and a test stress of 19,500 lb.

From the above and A. S. M. E. Code requirements for the reinforcement of openings, it can be easily calculated that where a considerable amount of the shell thickness is added for corrosion allowance, an excess of opening reinforcement must be added simply to provide strength for the hydrostatic test.

This is not only unnecessary and uneconomical but the reinforcing pads on large openings, on account of their great thickness and area, are setting up harmful stresses in the vessel wall adjacent to the edges of the pad. These stresses are much higher along lines tangential to the edges of the pad and at right angles to the circumferential axis of the opening than at the edges arcing the longitudinal axis of the opening. In addition to adding this stiffness which is a structural weakness, the problem of welding in such heavy structures is a grave one. A hydrostatic test is not necessary to prove the efficiency of radiographed shell welds; it is, however, of the greatest importance in detecting structural weaknesses and leaks around openings. For the reasons enumerated, test requirements are recommended in accordance with Figs. 8 and 9. The stresses given in these tables are based on the nozzle reinforcement being one hundred per cent efficient when whatever corrosion allowance that has been added is gone. Also, the reinforcing effect of the additional metal on the inside of the nozzle neck and the reduced diameter of the nozzle before corrosion, are taken into account. Believing that one hundred per cent joint efficiency should be allowed for a Class 1 weld, the stresses given in these tables are based on one hundred per cent joint efficiency. You will note that as the stress in the shell decreases the stress in the nozzle reinforcement slightly increases. Therefore, using these recommended tests the only questionable parts of a Class No. 1 vessel, that is, openings and their reinforcement, are being tested to within approximately 80 per cent of their yield point,

$\frac{T-t}{T}$	$\frac{(T.P.)}{P}$	Stress Lb./Sq. In. While under Test Pressure ($T.P.$) In Shell at Long. Joints	In Nozzle Reinforcing
0%	2.0	22,000	22,000
10%	1.99	21,900	23,500
20%	1.945	21,400	24,900
30%	1.865	20,500	26,200
40%	1.745	19,200	27,500
50%	1.50	16,500	27,500

T = Thickness of cylinder wall (inches) at time of fabrication
t = Corroded thickness of cylinder wall (inches)
$T - t$ = Corrosion allowance
$(T.P.)$ = Test pressure (lb./sq. in.)
P = Design pressure (lb./sq. in.)—based on thickness "T" and allowable stress at atmospheric temperature

Proposed test pressures (Unfired P. V. Section A. S. M. E. Boiler Code).
Resultant stresses in nozzle reinforcings and in shell at longitudinal joints.

Fig. 8

$\frac{T-t}{T}$	$\frac{(T.P.)}{P}$	Stress Lb./Sq. In. While under Test Pressure ($T.P.$) In Shell at Long. Joints	In Nozzle Reinforcing
0%	1.5	20,600	20,600
10%	1.49	20,500	22,000
20%	1.46	20,100	23,400
30%	1.40	19,300	24,600
40%	1.32	18,200	26,200
50%	1.20	16,500	27,500

T = Thickness of cylinder wall (inches) at time of fabrication
t = Corroded thickness of cylinder wall (inches)
$T - t$ = Corrosion allowance
$(T.P.)$ = Test pressure (lb./sq. in.)
P = Design pressure (lb./sq. in.)—based on thickness "T" allowable stress at atmospheric temperature

Proposed test pressures where factor of safety is reduced to 4.
Resultant stresses in nozzle reinforcings and in shell at longitudinal joints.

Fig. 9

plus the added stress due to the surge of the hammer test.

Comparison of Stress Formulae

Figure 10 is a comparison of stress equations in closed cylinders with a uniform internal pressure. A very considerable number of strain gage readings taken on a wide variety of welded vessels under hydrostatic test indicate that Clavarino's formula is most exact when assuming Poisson's ratio as point 30, at least at normal temperatures. This formula, however, is a very complicated one and one that few inspectors could use. The use of the common formula, as given in the A. S. M. E. Boiler Code, results in a slightly too heavy wall for thin walled vessels and much too thin a wall for heavy walled vessels. Therefore, it is necessary to jump to another formula, but in jumping to Barlow's formula, as the Boiler Code does, a much too heavy wall thickness is the result. Lamé's formula is practically the same as Clavarino's except that Lamé does not take Poisson's ratio into consideration. The proposed Mean Radius formula is a transposition of Lamé's formula which puts this equation into a simple form that any inspector can use.

You will note how closely the curve of this formula parallels that of Lamé and that the result in wall thicknesses is more conservative than Clavarino, until we get to a condition where the wall thickness is more than seventeen per cent of the inside diameter. (More complete discussion of the comparison of these formulae will be found in the appendix to this paper.)

It is a fundamental rule that the thinner one can make the wall of a tube or vessel, operating under internal pressure and with unequal temperatures inside and out, the better is the design. Therefore, the use of this Mean Radius formula is strongly indorsed.

Allowable Stresses in Carbon Steel

Considering the physical properties and structure of carbon steel usually employed in the construction of pressure vessels, we realize that the material now available is of much more uniform quality and strength than was available in former years. The German Boiler Code no longer adheres to a factor of safety of five, and the same may be said of certain classes of pressure vessels constructed in this country. On the whole, it appears that a factor of safety of four on the ultimate tensile strength of material manufactured to present specifications seems entirely justified. The ultimate strength is chosen as a basis of the physical properties rather than the yield point or proportional limit, since these latter values vary greatly as determined by different laboratories. One-fourth of the ultimate tensile strength within the temperature range covered, that is, up to 650 deg. Fahr., will always be less than one-half of the yield point.

When operating at temperatures above 650 deg. Fahr. creep must be taken into consideration. Creep affects the life of a structure and, therefore, some definite life has to be assumed. In the petroleum industry five years is commonly used as the basis of replacement, and in the curve which I will show you shortly, a life of 50,000 hrs., or approximately six operating years, has been used. Five per cent creep in 50,000 hrs. or one per cent in 10,000 hrs. has been used as a criterion of design in the creep range. One per cent in 10,000 hrs. is the most common creep rate used by different investigators, and a total extension of five per cent in ductile metal such as carbon steel is conservative for tubes and pressure vessels in view of past experience. The percentages of creep mentioned apply to tensile tests on laboratory specimens.

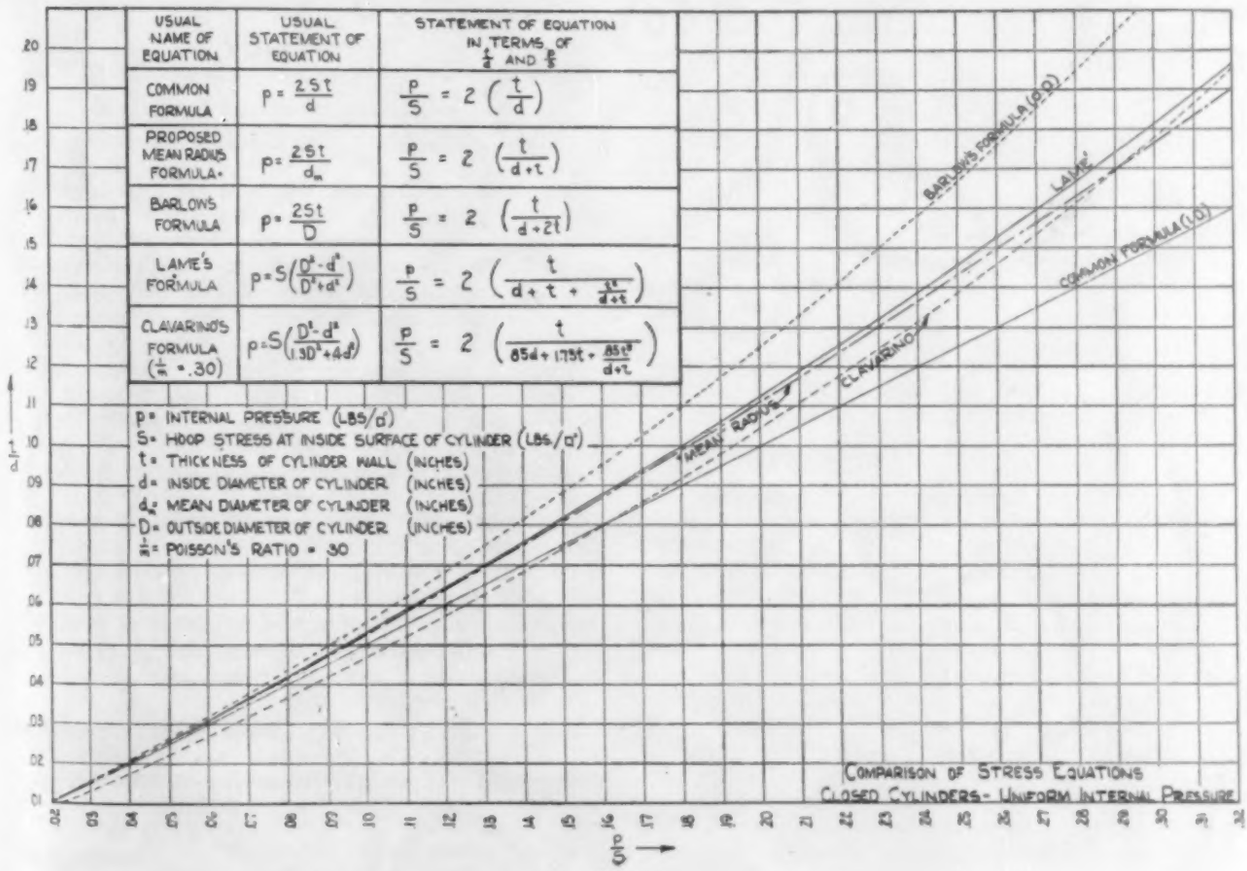

USUAL NAME OF EQUATION
USUAL STATEMENT OF EQUATION
STATEMENT OF EQUATION IN TERMS OF t/d AND P/S
COMMON FORMULA
PROPOSED MEAN RADIUS FORMULA*
BARLOWS FORMULA
LAME'S FORMULA
CLAVARINO'S FORMULA (1/m = .30)
P = INTERNAL PRESSURE (LBS/□")
S = HOOP STRESS AT INSIDE SURFACE OF CYLINDER (LBS/□")
t = THICKNESS OF CYLINDER WALL (INCHES)
d = INSIDE DIAMETER OF CYLINDER (INCHES)
d_m = MEAN DIAMETER OF CYLINDER (INCHES)
D = OUTSIDE DIAMETER OF CYLINDER (INCHES)
1/m = POISSON'S RATIO = .30
BARLOW'S FORMULA (P/D)
LAME'
COMMON FORMULA (1/D)
MEAN RADIUS
CLAVARINO
COMPARISON OF STRESS EQUATIONS
CLOSED CYLINDERS - UNIFORM INTERNAL PRESSURE
t/d
P/S

Fig. 10

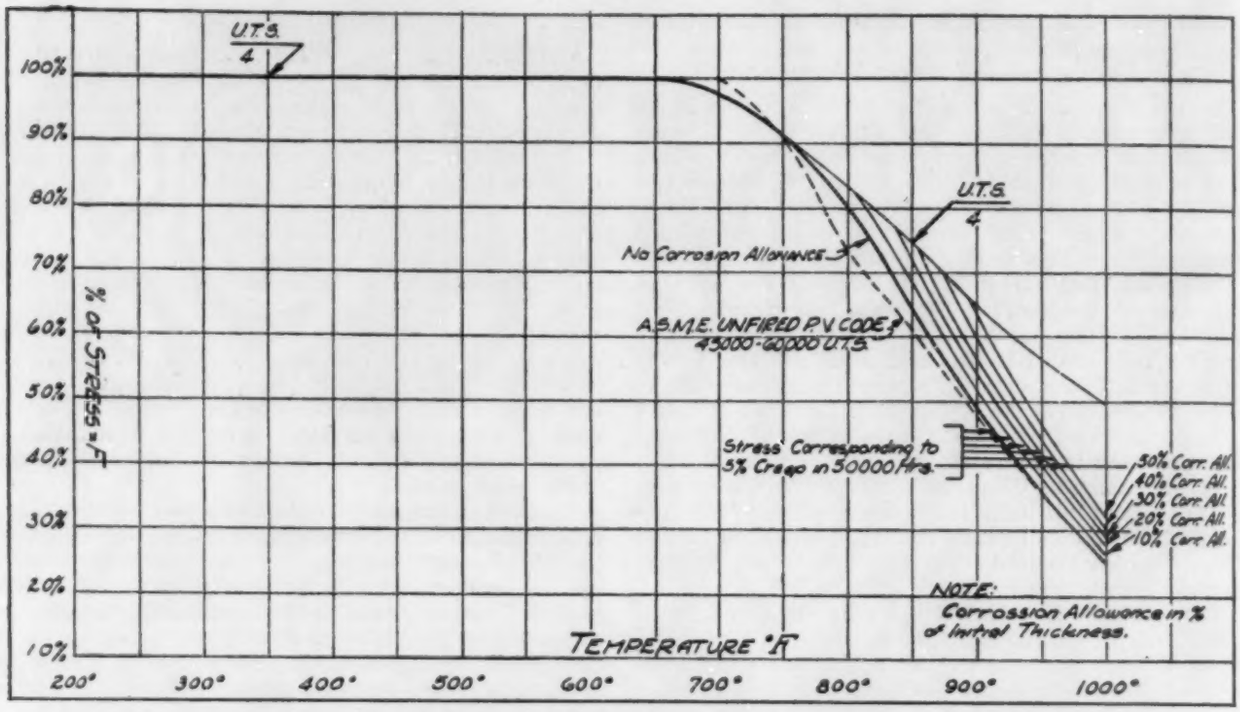


Fig. 11—Recommended Allowable Stresses—Carbon Steel

It is generally recognized that there is a reduced rate of creep under the compound stresses of a hydrostatic system. (See Bailey Symposium 1931.) For the present, actual operating data collected by the petroleum refining industry indicates that these compound stresses may be considered as a factor tending to reduce the total amount of creep to be expected in a given length of time.

Figure 11 is a curve or family of curves of allowable stress, the heavy line on which is the recommended stress curve. In the creep range it will be noted that the allowable stress curve is in reality a series of curves which are marked "No Corrosion Allowance," "10% Corrosion Allowance," etc. Corrosion allowance will naturally lower the internal stress in the walls of a vessel and, if the corrosion proceeds at a uniform rate, the fiber stress will increase inversely to the thickness. In other words, the effect of creep is materially postponed.

(An appendix to this paper gives an outline of the mathematics, together with the slope and intercept values used in the determination of these curves.)

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The reason for mentioning hydrostatic test and allowable operating stresses in this paper is that if the recommended hydrostatic tests and the recommended curve with modifications, taking corrosion into consideration, are adopted, wall thicknesses, particularly for vessels operating at elevated temperatures, will be materially reduced, resulting in the improvement of design and less difficult fabricating problems.

In the first half of this paper I have told of the difficult problems connected with heavy welded structures. All of these have been overcome by experience and effort and by the expenditure of large sums of money, yet there are many purchasers, manufacturers of welding machines and fabricators who believe that just because there are specifications and codes, that the overcoming of these problems is easy. Specifications and codes are necessary for a minimum basis of design, but it is my contention that the experience and integrity of the manufacturer is the cheapest insurance the purchaser can buy.

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APPENDIX

Comparison of Stress Equation

Closed Cylinders—Uniform Internal Pressure

The five equations in common use for determining the stress at the inside surface of closed cylinders under uniform internal pressure are compared graphically. A further comparison is made of these formulae by a tabular statement in terms of t/D and p/S, which terms are also used as abscissa and ordinate for the plot.

You will note that the proposed "Mean Radius" or "Diameter Formula" differs from the common formula only by the addition of "t" to the denominator. In Barlow's formula, the denominator is $d + 2t$. Lamé's formula has an additional term in the denominator of $t2/d + t$; for values of t/d of 0.15, an error of less than 2% is introduced. This ratio of wall thickness to diameter covers all usual pressure vessel design.

It will be noted that the value of Poisson's ratio used in Claverino's formula is 0.30. As Poisson's ratio decreases in value, this formula approaches Lamé's formula with Poisson's ratio equal to 0, the formulae are identical.

Integration of Varying Creep Due to Corrosion

Equation of a straight line on log-log paper.

(1) $$y = mx^n$$

Let y = creep rate in per cent per hour
x = stress in lb. per sq. in.

Then m = intercept of the line on the y axis or the unit creep rate
n = tangent slope of the line (relative to the y axis)

Initial Stress = $S = \frac{PR}{T}$ (Common formula)
a = rate of corrosion in per cent of "T" per hour
T = initial thickness
z = time in hours

Then thickness after z hours = $T(1 - az)$

Substitute in (1)

$$y = m\left[\frac{PR}{T(1 - az)}\right]^n$$

$$y(dz) = m\left[\frac{PR}{T(1 - az)}\right]^n$$

Total creep in "h" hours = C

$$C = m\int_o^{z=h}\left[\frac{PR}{T(1 - az)}\right](dz)$$

$$C = ms^n\int_o^h \frac{(dz)}{(1 - az)^n}$$

$$\int_o^h \frac{(dz)}{(1 - az)^n} = \frac{1}{a(n - 1)}[(1 - ah)^{1-n} - 1]$$

Therefore

$$C = \frac{ms^n}{(1 - az)^n}[(1 - ah)^{1-n} - 1]$$

Check:
Let $a = 0$; that is, no corrosion

Then

$$C = ms^n\left[\frac{(1 - ah)^{1-n} - 1}{(1 - az)^n}\right] = ms^n\left[\frac{0}{0}\right]$$

Indeterminate. Therefore, differentiate the terms in the brackets.

$$\frac{f'(a)}{\phi'(a)} = \frac{(1 - n)(1 - ah)^{-n}(-h)}{(n - 1)}$$

$$= \frac{(n - 1)(1 - ah^{-n})(h)}{(n - 1)}$$

$$= (h) \qquad \text{when } a = 0$$

Therefore

$$C = (ms^n)h$$

Truth Is Stranger than Speculation

By **GILBERT E. DOAN**

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MR. HOLSLAG'S speculations in the April Journal about the strength of metals and about the cohesion of one metal to another when welded, are without question stimulating hypotheses and examples of ingenious logic. That these speculations do not correspond with the facts, as far as science knows them today, should perhaps be pointed out. But it is even more interesting to observe that the facts are actually stranger than speculation would deduce.

The strength of metals does not depend upon "interlocking and intertwining that knits substances together and gives them their strength," as Mr. Holslag proposes. The crystal grains of the metal iron, for instance, are smooth-sided polyhedrons without any substantial interlocking as is shown in the micrograph in Figure 1*a*, yet iron is a strong metal. After hot rolling or forging, in which state metals are strongest, they still have smooth grain boundaries. The appearance of these smooth grain boundaries leads one to the conclusion that the grains could easily be pulled apart. As a matter of fact, strange though it is, the cohesion between the boundaries is stronger than the grains themselves, and fracture of

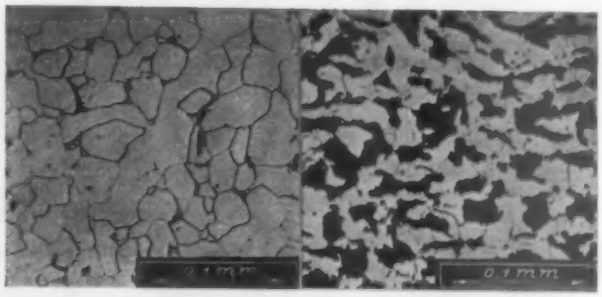

Fig. 1 (*a*)—Smooth Sided Grains of Iron **Fig. 1 (*b*)—Pearlite and Ferrite in Steel**

(From Liddell and Doan, "The Principles of Metallurgy," McGraw-Hill Book Co., 1933.)

metal of the ordinary kind always takes place *through* the grains and not *between* them, however smooth their boundaries may be. A satisfactory explanation of this mysterious fact has not yet been discovered. At high temperatures or in the presence of certain impurities at the grain boundaries, or under corrosive conditions, it is true that the grains may pull apart so that the smoothness of the grain boundaries can be seen in the fracture, as in Fig. 2, but at ordinary temperature and under ordinary conditions of use the fracture of the same specimen goes *through* the grains and not between them. If there is any interlocking here, it must be *inside* the grains and not between them.

Likewise, the hard grains of iron carbide in a plain carbon steel have relatively smooth boundary planes, as shown in Fig. 1*b*, but break *through* the grain instead of *between* the carbide and the iron grains. These harder grains of carbide do stiffen the soft matrix of iron as the bony skeleton does the body of an animal, but it is not in an interlocking or "intertwining" or "glueing"

Fig. 2—Inter-Crystalline Fracture in Cast Bronze at High Temperature. × 2

(Photo by Mr. A. M. Bounds in the writer's laboratory.)

effect as much as it is a simple obstruction to flow of the metal under stress.

Carbon above about 1 per cent makes iron brittle due to an excess of the very hard (and brittle) carbide between the grains. In gray iron it forms "flakes" of graphite which are planes of weakness in the metal. Manganese in Hadfield steel, chromium and nickel in stainless steels and many another alloy element does not form a new kind of grain at all when added to iron, as shown in Fig. 3, but dissolves atomically in the crystals of iron, replacing some of the native iron atoms in the crystal lattice of the iron grains. There is no visible change in shape of the grains such as to indicate interlocking with each other. In these alloys also fracture is usually *through* the grains and not *between* them. In this case (solid solution) the metal is usually strengthened far more than in the case where a new kind of grain is introduced into it (duplex structure). But the strengthening of the iron grains themselves by the substituted nickel or chromium atoms can scarcely be explained as an interlocking effect. It seems rather to be due to an electrical or magnetic attractive force between the native and the stranger atoms *within* each grain.

Heat treatment and welding of steel and other alloys do produce changes in the size and shape of the grains, but the cohesion between the boundaries, even if the latter are smooth, as in a quenched 14 per cent manganese steel in Fig. 3, still is stronger than the grains themselves, and fracture will go *through* the grains rather than *between* them. Heat treatment strengthens the grains tremendously but does not make them as strong as the bond between neighboring grains.

Neither does welding nor brazing and soldering depend upon an interlocking of grains. If two perfectly smooth machined and polished metal surfaces are brought into

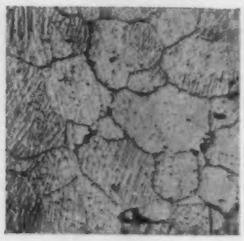

Fig. 3—Quenched 14 Per Cent Manganese Steel

contact, *without pressure or heating*, they will cling to each other so tightly that forcible separation tears bits of metal out of the opposite faces. Such surfaces are quite difficult to prepare but the experiment is also very illuminating. The essence of welding is, therefore, the attainment of clean and intimate contact, whether it is produced by heating and fluxes with pressure, or by melting, or by machining and polishing.

The visible internal structure of a metal does, it is true, play an important part in making up the physical properties of the metal, just as the stone and steel in a skyscraper or the steel and concrete in a bridge determine the strength and resilience of the structure. But cohesion between grains and cohesion within each individual grain, as well as cohesion of welded surfaces, must be explained in terms of electrical and magnetic forces between atoms—a far less definite and picturesque explanation than the hypothesis which Mr. Holslag has so ingeniously proposed, but also a more fundamental one.

Compression Test of Welded Steel

By **CHARLES MOSER**

✦Prof. Charles Moser is connected with Leland Stanford University. Material submitted as report to Fundamental Research Committee of American Bureau of Welding.

Purpose.—The tests herein reported were made in order to compare the elastic properties of welded and unwelded steel plate.

Material.—Steel plate and welding rods employed were taken from stock used in former tension tests and are described in report on "Elevated Temperature Tests of Welds," JOURNAL of AMERICAN WELDING SOCIETY for September 1927–1928. The following is an abbreviated quotation:

"Specimens were prepared from 5-ft. x 10-ft. sheet of fire-box steel with following characteristics:

Carbon	0.15 ± %
Proportional limit	31,000 lb. per sq. in.
Tenstile strength	66,000 lb. per sq. in.
Elongation in 8 in.	27%

"Welding Rod No. 1. A self-fluxing acetylene rod which showed unbreakable welds in machined section.

"Welding Rod No. 13. A low-carbon acetylene rod (0.055% C) showing low strength and extreme ductility of weld metal.

"Welding Rod No. 11. A low-carbon electrode (0.082% C) with no outstanding properties.

"Welding Rod No. 21. A low-carbon electrode (0.144% C) which showed good strength for its type."

Suggested Procedure in Specimen Preparation

1. Take plate 8 in. x 12 in. and cut first with saw or narrow milling cutter to 8-in. x 6-in. plates (cutting

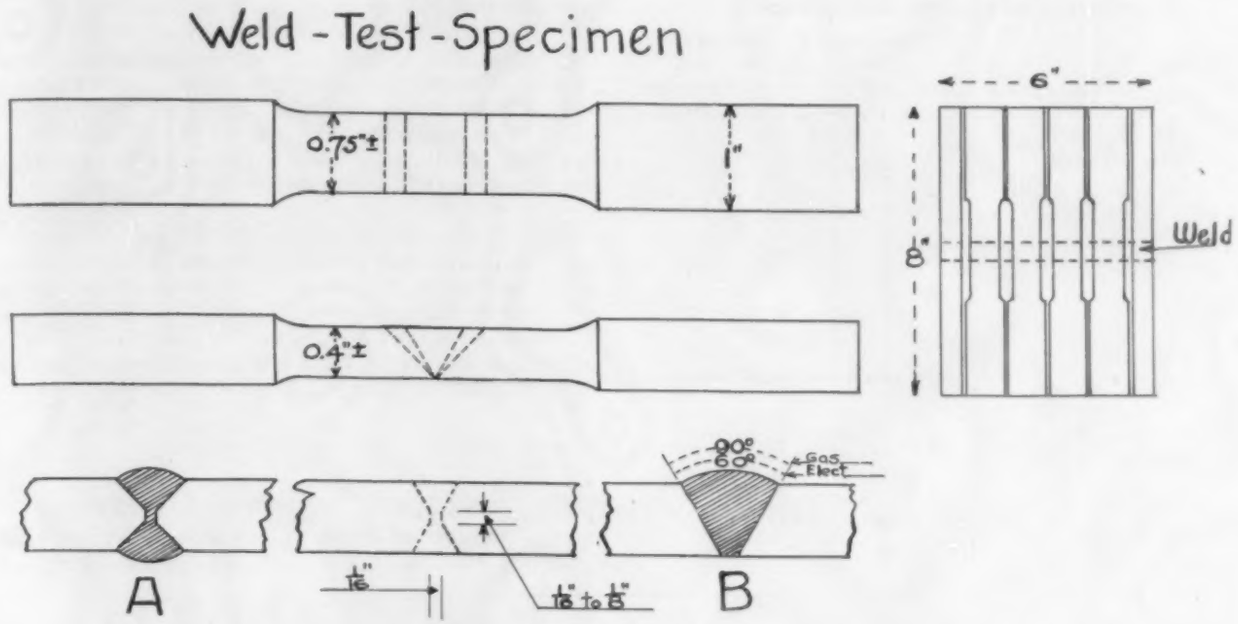

Fig. 1

Two halves should be aligned with special care so shanks of finished specimen will be in line without machining shanks.
Scarf to be *machine cut*. Torch must not *be used* to *cut plate* or *scarf*.
Specimen plates when finished to be 6 in. x 8 in. ($^1/_2$ size of plates furnished).
Each 6-in. x 8-in. plate (weld across 6-in. dimension) to make 4 specimens like above.
Specimens to be machine cut from plate after welding.
Reduced section or waist to be machined to uniform section, i.e., opposite sides parallel. Do not allow milling cutter to run against specimen at either end of cut on waist with feed disconnected.
Take one 6-in. x 8-in. plate without weld and cut 5-in. specimen from it as parent metal or "control" specimens.

torch may be used on this cut if low acetylene pressure is used so heat is a minimum. A machine cut is much to be preferred however).

2. Place 8-in. x 6-in. plates in shaper or planer and make welding scarfs in operation of cutting into 4-in. x 6-in. plates preparatory to welding. The same halves of 8-in. x 6-in. plates should be welded together again and not mixed with other plates. This calls for numbering system as outlined in Par. 10 of this procedure.

Each 8-in. x 12-in. plate furnished now carries a small number stamped in the metal. This number indicates the position of this plate in the original plate purchased and identifies the specimen plate. This number should be used in identifying each specimen from this plate. Both welds with a given rod, i.e., one single V and one double V, should be made from one plate in order to have the plate metal as near identical as possible for comparison of the two types of weld.

3. Scarfs to be of four types and two plates made of each type (sixteen in all) as follows:

(*a*) 2 Electric welds, double V
(*b*) 2 Electric welds, single V
(*c*) 2 Gas welds, double V
(*d*) 2 Gas welds, single V

4. Welds to be made in a jig so as to insure alignment as accurately as possible of two halves of specimen as unmachined shanks must line up in testing machine.

5. Stripping specimens from plates must *not* be done with the torch but with $^1/_8$-in. mill or planer cut. The torch will alter the structure of the metal on the edges and warp the specimens. Four specimens from each plate as indicated in attached sketch. Make the trim on the edges as much as possible and about equal on each edge, thus eliminating the start and finish of the weld.

6. In milling off the reduced section of specimen special care should be taken to have opposite faces accurately parallel. The value of the specimen and the results depend on the care used in this operation.

7. A reference set of specimens, of the same dimensions, but without welds to be prepared from one of the 8-in. x 6-in. plates of solid metal. With narrow cuts 5 specimens can be prepared from this plate. If the necessary narrow cutter is not available 4 should be sufficient. These specimens are to be used to determine the properties of the original plate.

Mr. K. V. Laird of the San Francisco Section, A. W. S. outlined the procedure in preparation of specimens. The specimens were made up by a local firm.

Testing.—(*a*) Heavy accurately squared clamps were placed on ends of each specimen to form a fixed-end column 3 in. in length. Loads were recorded for each 0.0006-in. deformation of middle 2 in. of column to beyond proportional limit. The load required to show proportional limit did not produce noticeable bending of specimen.

Testing.—(*b*) After test to determine elastic properties, the specimens were cut down to $1^1/_4$-in. length for crushing test. The purpose of crushing test was to study the behavior of welds under excessive deformation. The specimens were loaded as square end struts and compressed to $^7/_8$ in. or less in length. Occasional observation of final loads showed that approximately 50,000 lb. was required to shorten specimen to 0.6 of its original length. Representative samples of crushing, numbered as in tests for elastic properties, are submitted without further comment for examination. Shape of specimens before crushing is shown by undeformed sample approximately 0.4 x 0.75 x 1.25 in.

Compression Tests of Welded Steel

Specimen No.	Weld	Proportional Limit, Lb. per Sq. In.	Modulus of Elasticity, Lb. per Sq. In.
11	Gas	27,000	26,000,000
12	Rod No. 1	29,000	24,000,000
13	Single V	26,000	27,000,000
14		23,000	25,000,000
15	Gas	26,000	28,000,000
16	Rod No. 13	20,000	23,000,000
17	Single V	25,000	25,000,000
18		24,000	27,000,000
21	Gas	24,000	27,000,000
22	Rod No. 1	23,000	29,000,000
23	Double V	23,000	28,000,000
24		19,000	23,000,000
25	Gas	24,000	28,000,000
26	Rod No. 13	20,000	25,000,000
27	Double V	26,000	28,000,000
28		30,000	26,000,000
31	Electric	29,000	27,000,000
32	Rod No. 11	29,000	26,000,000
33	Single V	32,000	27,000,000
34		32,000	26,000,000
35	Electric	27,000	27,000,000
36	Rod No. 21	27,000	27,000,000
37	Single V	25,000	26,000,000
38		28,000	26,000,000
41	Electric	29,000	26,000,000
42	Rod No. 11	26,000	25,000,000
43	Double V	26,000	26,000,000
44		28,000	26,000,000
45	Electric	30,000	26,000,000
46	Rod No. 21	26,000	26,000,000
47	Double V	29,000	25,000,000
48		26,000	27,000,000
01	Plate	32,000	30,000,000
02	Without weld	32,000	30,000,000
03		31,000	30,000,000
04		31,000	29,000,000
		Average Values	
11–48	32 welded specimens	26,100	26,200,000
01–04	4 unwelded specimens	31,500	29,700,000

HOW TO WELD IT

Inquiry: How Do You Spot Weld Copper Sheets Large Size?

H. A. WOOFTER, Chief Engineer, Swift Electric Welder Co.: "Our experience in spot welding copper has been that the size of the sheet, as far as square inches or square feet of area is concerned, has no effect on the good or bad results of the welding, but the thickness of the sheet does have a great deal to do with it.

"It is fairly common practice to weld thin sheets of copper by the spot welding process, but as the thickness of the sheets increases above about 0.035, the difficulties increase in the value of geometrical ratio. The reason for this is that the high thermal conductivity of the copper causes it to steal the heat away from the vicinity of the weld and the thinner the sheets the less copper adjacent to steal away heat. Conversely, with thicker sheets there is more copper adjacent to the spot and the heat is stolen away more quickly and it is more difficult to bring the metal up to a welding temperature.

"We have successfully spot welded two $^1/_8$-in. copper sheets, but it takes an enormous amount of power and a very large quick acting spot welder to make welds in this thickness of stock. The matter of welding thin copper sheets is becoming more and more common and easier each day, owing to the great refinements in the spot welding machine itself wherein synchronous control devices are used that give a certain amount of power per weld and give it very quickly, which is just what is needed for spot welding copper sheets.

"In spot welding copper it is always best to use some special alloy for the spot welder tips, such as Elkaloy, Elkonite or Berillian Copper. If this is not done, the spot welder points will not stand up very long and the amount of dressing required is excessive. The Elkonite tip lasts the longest when spot welding copper, but its initial cost is quite high. However, it usually is economy in the long run to use the Elkonite points for spot welding copper."

I. T. HOOK, Research Engineer, The American Brass Company: "In resistance welding of copper, the following points must be given careful consideration:

"(*1*) *Electrical Conductivity.*—Electrolytically refined or "tough pitch" copper has the highest electrical conductivity of any of the commercial metals. In general, this means that very high current values or heat settings must be used. Very frequently the spot welding transformers which work very satisfactorily on steel, have much too low a capacity for copper. As an illustration, a 100 kv-a. resistance seam welder which welded steel sheet with a heat setting of 5, had insufficient heat for copper with a heat setting of 16 (maximum capacity).

"(*2*) *Heat Conductivity.*—This property is also very high for a commercial metal, necessitating a high degree of heat. Even if a high resistance metal is used as a weld metal between the copper sheets, a high degree of

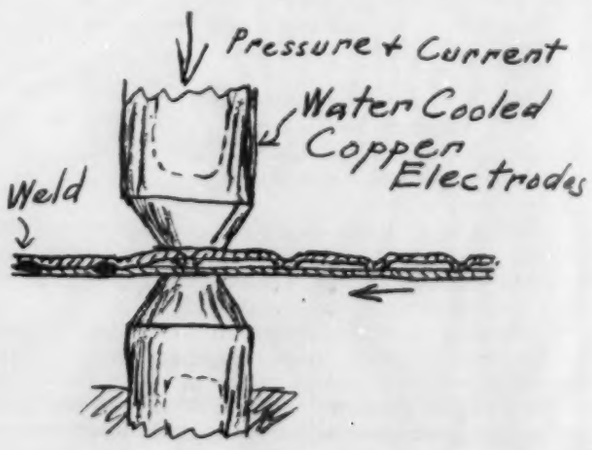

Fig. 1

heat must be used to bring the copper up to a temperature at which it will alloy with the weld metal.

"(3) *Electrodes.*—The high heat requirement is very bad for the copper electrodes. The latter become softened and squash out quickly, necessitating very frequent renewals. If no other factors were involved, the constant redressing of the electrodes, single points or wheels may make the process too costly for commercial application.

"The writer suggests that the best chance for success would be in the use of projection points, as in Fig. 1. In this case wide, flat-nosed copper electrodes can be used with comparatively little wear or distortion.

"(4) *Weldability of Copper.*—While copper is readily welded, the welding is done with fluid metal. In other words, copper does not have a plastic, weldable range as does steel but it must actually be melted to secure a strong weld.

"(5) *Welding with Interposed High Resistance Weld Metal.*—Perhaps the most practical method of resistance welding of copper is to place between the copper sheets a narrow, thin strip of a high resistance metal which will melt at a temperature when the copper itself is at a bright red. Phosphor bronze is such a metal. Used in a thickness of approximately 0.010 in., the phosphor bronze will melt and alloy with the copper while the latter is at a bright red. A strength approximating that of soft copper will be obtained.

"The use of such a high resistance strip, in addition to the projections and flat electrodes of Fig. 1, appears to offer the best solution to the problem."

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